



US Army Corps
of Engineers



AD-A227 528



TECHNICAL REPORT EL-90-9

2

PROPOSED 9TH INFANTRY DIVISION FORCE CONVERSION; MANEUVER DAMAGE, EROSION AND NATURAL RESOURCES ASSESSMENT YAKIMA FIRING CENTER, WASHINGTON

VOLUME I: MAIN TEXT

by

L. Jean O'Neil, Michael R. Waring, H. Glenn Hughes, Mary C. Landin

Environmental Laboratory

and

Monte L. Pearson, Patricia A. Morris, Robert J. Larson

Geotechnical Laboratory

DEPARTMENT OF THE ARMY

Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199



August 1990

Final Report

DTIC
ELECTE
OCT 17 1990

E

D

Approved for Public Release; Distribution Unlimited

Prepared for DEPARTMENT OF THE ARMY
US Army Engineer District, Seattle
Seattle, Washington 98124-2255

Project No. E87-893153

Destroy this report when no longer needed. Do not return it
to the originator.

The findings in this report are not to be construed as an
official Department of the Army position unless so
designated by other authorized documents.

The contents of this report are not to be used for
advertising, publication, or promotional purposes.
Citation of trade names does not constitute an
official endorsement or approval of the use
of such commercial products.

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Report EL-90-9			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZATION USAEWES, Geotechnical and Environmental Laboratories		6b. OFFICE SYMBOL (If applicable) CENPS	7a. NAME OF MONITORING ORGANIZATION		
6c. ADDRESS (City, State, and ZIP Code) 3909 Halls Ferry Road Vicksburg, MS 39180-6199			7b. ADDRESS (City, State, and ZIP Code)		
8a. NAME OF FUNDING/SPONSORING ORGANIZATION USAED, Seattle		8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
8c. ADDRESS (City, State, and ZIP Code) Seattle, WA 98124-2255			10. SOURCE OF FUNDING NUMBERS		
			PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.
			See reverse		WORK UNIT ACCESSION NO.
11. TITLE (Include Security Classification) Proposed 9th Infantry Division Force Conversion; Maneuver Damage, Erosion, and Natural Resources Assessment, Yakima Firing Center, Washington, Volume I: Main Text					
12. PERSONAL AUTHOR(S) See reverse.					
13a. TYPE OF REPORT See reverse.		13b. TIME COVERED FROM _____ TO _____		14. DATE OF REPORT (Year, Month, Day) August 1990	
15. PAGE COUNT 118					
16. SUPPLEMENTARY NOTATION Plates are published separately in Volume II: Both volumes are available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP			
			Off-road mobility		
			Erosion effects		
			Maneuver damage		
			Environmental impacts		
19. ABSTRACT (Continue on reverse if necessary and identify by block number)					
<p>This study was conducted to determine the impact of a proposed conversion from a motorized to a mechanized force structure by the 9th Infantry Division Motorized (9ID MTZ) I Corps on the Yakima Firing Center, WA, study area. The study provides (a) an assessment of vehicle off-road mobility and maneuver damage, (b) an assessment of future erosion effects, (c) an assessment of the natural resources impact of maneuver damage addressing four force structures related to the possible I Corps mechanization, and (d) recommendations for management and mitigation.</p> <p>Volume I of this report contains the text analysis of this study, and Volume II contains oversized plates of maps describing vehicle mobility, maneuver damage disturbance levels, soil erosion, and environmental factors.</p>					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL			22b. TELEPHONE (Include Area Code)		22c. OFFICE SYMBOL

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

10. PROJECT NO. (Continued).

E87-893153

12. PERSONAL AUTHOR(S) (Continued).

O'Neil, J. Jean; Waring, Michael R.; Hughes, H. Glenn; Landin, Mary C.; Pearson, Monte L.; Morris, Patricia A.; Larson, Robert J.

13. TYPE OF REPORT (Continued).

Final report (in two volumes)

Accession For	
DTIC GRA&I	<input checked="checked" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By _____	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	



Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

EXECUTIVE SUMMARY

The US Army Engineer Waterways Experiment Station (WES) conducted a study to determine the impact of a conversion from a motorized to a mechanized force structure by the 9th Infantry Division Motorized (9ID MTZ) I Corps on the Yakima Firing Center (YFC), WA, study area. Specifically, WES provided (a) an assessment of vehicle mobility and maneuver damage, (b) an assessment of future erosion effects, (c) an assessment of the natural resource impact of maneuver damage addressing four force structures related to the possible I Corps mechanization, and (d) recommendations for management and mitigation.

The Army Mobility Model (AMM), which uses empirical mathematical algorithms to predict the performance of a vehicle on a terrain in terms of speed, and a digital terrain data base for the study area were used to predict maneuver damage based on the sinkage of the vehicles and the effect of soil disturbance due to tire and track slip and turning. These predictions were made for three vehicles representing the components of four vehicle force structures made up of armored, mechanized, and motorized divisions, respectively. They were the M998 High Mobility Multi-Purpose Wheeled Vehicle (HMMWV) representing the 3-3-5* and 4-3-3 force structures, an 8X8 wheeled combat vehicle also representing the 4-3-3 force structure, and the M60A3 Combat Tank representing the 5-5-0 force structure. Predictions were made for the dry normal and wet slippery surface conditions.

Rut Depth Relations

The fundamental relations of single tire sinkage on the first pass as a function of vehicle parameters such as the tire height, width, diameter, and deflection, and soil strength, wheel load, and slip were determined empirically from controlled laboratory tests in fine-grained soils and remoldable sands (Freitag 1965). These relations were modified based on several field test programs that required a detailed assessment and update of predictive relationships for vehicle traction, motion resistance, and sinkage. One-pass

* The 3-3-5 force structure designation refers to the number of armored, mechanized, and motorized battalions, respectively (i.e., 3 armored, 3 mechanized, and 5 motorized battalions). All other force structure designations follow the same convention.

wheeled vehicle rut depth versus soil strength (RCI) relations were obtained by substituting specific study vehicle parameters at a constant slip value of 20 percent. Studies have indicated that 20 percent wheel slip for most vehicles in fine-grained soils is the point of maximum drawbar horsepower efficiency (or vehicle work output index). The vehicle's ground clearance was used as the maximum wheel sinkage because a vehicle operating in soft soils will generally immobilize when its undercarriage drags on the soil surface. The relations were expanded to include a single track where first pass sinkage was a function of the track width, length, and soil strength (Turnage 1973). The relations were further adjusted based on vehicle tests and VCI_1 (see definitions, paragraph 5) data. This led to the development of the present first pass rut depth versus soil strength (RCI) relations for wheeled and tracked vehicles traveling in a straight path.

These first pass relations were used as a basis along with VCI_{50} data and some 50 and limited 500 pass test results to establish multi-pass (i.e., in the same rut) relations. Additional methodology was developed from limited field data for adjusting these relations to account for terrain, slope, and vehicle steering influences (turning for wheeled vehicles and pivoting for tracked vehicles). These data indicated that wheeled and tracked vehicles produced rut depths on slopes and when turning/pivoting which corresponded to those described for straight-line travel, but at RCI (see definitions, paragraph 5) values less than actual values used in the straight-line relationships (Willoughby and Turnage in preparation). Finally, the first pass relations, multi-pass relations, and adjustments to account for terrain, slope, and vehicle steering were used with the AMM to provide a model to predict soil disturbance due to vehicle traffic over an area. The model does not consider soil compaction below the soil disturbance depth nor does it consider the reduction of rock fragments by increased vehicle passes.

Maneuver Damage

It was determined that 10, 50, and 1,000 vehicle passes over the entire terrain of the potential traffic area presented the best estimate of the low, medium, and high tactical scenarios, respectively, in a training year for the YFC study area. Five classes of disturbance were established corresponding to depths of rutting to evaluate the effects of vehicle traffic on the study

area. They were minimal (0 to 1/2 in.), slight (>1/2 to 2 in.), moderate (>2 to 5 in.), high (>5 to 12 in.), and severe (>12 in.).

The following soil disturbance results were determined for the 3-3-5 and 4-3-3* force structures in the dry normal and wet-wet slippery surface conditions:

	Percent of Total Area**					
	10 Passes		50 Passes		1,000 Passes	
	D-N†	W/W-S††	D-N	W/W-S	D-N	W/W-S
Minimal disturbance	87.1(96.2)	58.5(64.6)	87.1(96.2)	0	0	0
Slight disturbance	0	0	0	58.6(64.7)	87.1(96.2)	46.2(51.0)
Moderate disturbance	0	0	0	0	0	12.3(13.6)
High disturbance	1.1(1.2)	0	1.1(1.2)	0	1.1(1.2)	0
Severe disturbance	0	0	0	0	0	0
NQGO	2.4(2.6)	32.1(35.4)	2.4(2.6)	32.0(35.3)	2.4(2.6)	32.1(35.4)
Urban/off-limits	9.4	9.4	9.4	9.4	9.4	9.4
Water	0	0	0	0	0	0
	100.0	100.0	100.0	100.0	100.0	100.0

* The principal vehicle for this force structure is the M998 (HMMWV).

** Values in parentheses indicate equivalent percents of the potential traffic area (all acres less urban/off-limits and water).

† D-N - dry normal surface condition.

†† W/W-S - wet-wet slippery surface condition.

The following soil disturbance results were determined for the 4-3-3* force structures in the dry normal and wet-wet slippery surface conditions:

	Percent of Total Area**					
	10 Passes		50 Passes		1,000 Passes	
	D-N†	W/W-S††	D-N	W/W-S	D-N	W/W-S
Minimal disturbance	75.5(83.4)	0.2 (0.2)	0	0	0	0
Slight disturbance	0	48.7(53.8)	75.5(83.4)	48.3(53.3)	75.5(83.4)	0.2 (0.2)
Moderate disturbance	0	0	0	0.6 (0.7)	0	48.7(53.8)
High disturbance	0	0	0	0	0	0
Severe disturbance	1.1 (1.2)	0	1.1 (1.2)	0	1.1 (1.2)	0
NOGO	14.0(15.4)	41.7(46.0)	14.0(15.4)	41.7(46.0)	14.0(15.4)	41.7(46.0)
Urban/off-limits	9.4	9.4	9.4	9.4	9.4	9.4
Water	0	0	0	0	0	0
	100.0	100.0	100.0	100.0	100.0	100.0

* The principal vehicle for this force structure is the 8X8 wheeled vehicle.

** Values in parentheses indicate equivalent percents of the potential traffic area (all acres less urban/off-limits and water).

† D-N - dry normal surface condition.

†† W/W-S - wet-wet slippery surface condition.

The following soil disturbance results were determined for the 5-5-0* force structure in the dry normal and wet-wet slippery surface conditions:

	Percent of Total Area**					
	10 Passes		50 Passes		1,000 Passes	
	D-N†	W/W-St†	D-N	W/W-S	D-N	W/W-S
Minimal disturbance	0	0	0	0	0	0
Slight disturbance	88.2(97.4)	5.1(5.6)	0	0	0	0
Moderate disturbance	0	45.4(50.2)	88.2(97.4)	0.2 (0.2)	29.6(32.7)	0
High disturbance	0	0	0	50.3(55.6)	58.6(64.7)	50.5(55.8)
Severe disturbance	0	0	0	0	0	0
NOGO	2.4(2.6)	41.1(44.2)	2.4(2.6)	40.1(44.2)	2.4(2.6)	40.1(44.2)
Urban/off-limits	9.4	9.4	9.4	9.4	9.4	9.4
Water	0	0	0	0	0	0
	100.0	100.0	100.0	100.0	100.0	100.0

** Values in parentheses indicate equivalent percents of the potential traffic area (all acres less urban/off-limits and water).

† D-N = dry normal surface condition.

†† W/W-S = wet-wet slippery surface condition

Effects of Vehicle Traffic on Soil Erosion

The processes of wind and water erosion in an arid environment were examined and used in an analysis of the erosional impact of possible military activity in the YFC. The analysis included the factors of soil, grain size, cohesion, crust formation, surface slope, climate, roughness, and organic content. Wind and water erosion algorithms were developed to include depth of soil disturbance by vehicles and factors for the number of vehicle passes for the study area. The wind and water erosion algorithms represent the dominant modes of erosion for the dry normal and wet-wet slippery surface conditions, respectively.

The impact of soil erosion during both the dry and wet cycle is presented in relation to allowable soil loss (soil erosion severity); a soil loss rate equal to the soil regeneration rate is a non-soil loss or equilibrium condition. Soil erosion estimates for each force structure and climatic condition are presented in map format. Soil erosion severity is presented as the maximum possible erosion for each 164- by 164-ft (50- by 50-m) parcel of the YFC. The assumption is that every parcel gets the maximum vehicle traffic considered in the analyses. The eroded soil may be transported to and deposited in an adjacent parcel with less than 10 percent of all the soil eroded from the parcels in the YFC area actually leaving the area. Erosion during the wet-wet slippery condition is considerably less than erosion during the dry condition.

Recommended methods of reducing soil erosion are given. Soil erosion can be minimized by restricting vehicle traffic to arteries between activity centers, avoiding areas underlain by loess (silty) soils, and scheduling vehicular activity to seasons (months) with the least wind and water erosion potential. Optimum planning of maneuvers to reduce soil erosion would incorporate all of these considerations. If the above recommendations are not implemented, the extent of erosion due to the combined effects of wind and water could cause unnecessary sediment transport to the Columbia River.

Natural Resources

The general topography of YFC (plateaus interfaced with intermittent stream beds and associated soil banks and rocky cliffs) and the low precipitation produce an ecosystem occupied by species that are highly adaptable to harsh climatic conditions. The most striking features of the YFC are Selah Creek Canyon, Alkali Canyon, and the bluffs and slopes leading to the Columbia River. These provide different habitats than the plateaus and broad hills covering most of the installation.

The primary natural resource impacts addressed in this study relate to the alteration or destruction of soil structure and vegetation and subsequent effects on fish and wildlife caused by the different force structures. The disturbances from traffic, as reported in earlier parts of this report, represent the worst case scenario in that all but the obvious exclusions (e.g., impact and dud areas) are assumed to be affected. Because of practical considerations such as constricted movement caused by topography, the actual impact may occur on a smaller percentage of the area. However, cumulative impacts on soils and vegetation from repeated use could bring the total impact on a localized area to 100 percent. Because of these ambiguities, specific acreages and locations are not reported; indices and percentages are used to show relative impacts among the various force structures.

Basis for impact assessment

Major components of the environment and wildlife habitat include water, topography, specific plant species, the physical structure of vegetation, and substrate. Of these components in the YFC, vegetation and soils are the most directly affected by vehicles, and will be used as the basis for evaluating the differential impacts of the three force structures.

The model used to predict soil disturbance from vehicles does not consider compaction, so this impact cannot be quantified. However, compaction from any source (wildlife or hiking trails, vehicles) negatively affects plants by reducing soil aeration and moisture-holding capacity so plant growth is reduced or eliminated. Effects on animals that live below the surface include death or displacement. The degree of impact depends on the severity of compaction. One way to estimate impacts is to examine changes in habitat complexity, based on the number of vegetation layers present. More complexity refers to the maximum number of layers for each type; e.g., the maximum number

of layers in an emergent wetland is less than in riparian forest. However, that does not reduce the importance of the wetland as a cover type and wildlife habitat.

Three layers have been identified on the YFC that contribute to habitat quality by increasing complexity when they are present and functioning. An estimate of the amount of vegetation lost in each of these layers, plus the amount of soil productivity lost for each level of disturbance, was used to predict the relative impact of each force structure.

The 3-3-5 force structure was used as the baseline for comparing relative impacts of the proposed force structures. In all cases, both wet and dry, the general trend appears to be an increase in the amount of impact as the force goes from 3-3-5 to 4-3-3 (8X8) to 5-5-0.

Effects on specific plants,
animals, and communities/habitats

Nine species of plants were considered to be of special interest, based on data from the Washington Natural Heritage Data System (WNHDS). These include the Columbia milk-vetch, basalt daisy, Hoover's desert-parsley, beaked spike-rush, porcupine sedge, giant belleborine, shinny flatsedge, Umtanum desert-parsley, and Henderson's ricegrass. Of these, only the basalt daisy, Hoover's desert-parsley, and the Umtanum desert-parsley are located in areas that will receive little or no impact.

The WNHDS also provided six bird species of concern, including the prairie falcon, golden eagle, ferruginous hawk, Swainson's hawk, sage grouse, and burrowing owl. All of these may be impacted to some degree from disturbance during the nesting season or from loss of habitat, either for the species of concern or for the prey that the species depends upon. The burrowing owl is already severely impacted; increased training levels will increase the likelihood of further severe impacts.

Two mammal species, the Merriam's shrew and sagebrush vole, will also be impacted. Impacts from increased training would range from vehicles crushing nests and young, to long-range impacts of changing vegetation and reducing sagebrush voles and their burrows, to increased bare ground reducing insects.

Communities and/or habitats of special concern include sagebrush, riparian springs and seeps, rocky areas, and cliffs. Sagebrush is greatly impacted in an area such as YFC in several ways. First, it is crushed or damaged by training vehicles. Second, wildfires that arise from training top-kills or

damages sagebrush. Third, as it tries to regenerate from roots or crushed stems, it is eaten by livestock and certain species of wildlife. Fourth, where bare ground areas are exposed, wind and water erosion removes topsoil from these dry washes and hilly slopes, and the sagebrush cannot form adequate root systems or maintain itself on eroded soils.

The creeks on the YFC have varying amounts of riparian vegetation. The riparian areas that are accessible (such as Selah Creek) are greatly affected by training, driving in the creekbed, and other uses. Continuous coverage of typical riparian vegetation does not occur in these areas, and there are areas with severe erosion. The shift to different force structures and higher training intensities will magnify this problem. Further degradation of the riparian area may be caused by fording or crossing, especially at undesignated sites.

Springs and seeps all have wetland or vegetation communities different from the surrounding steppe vegetation, and can be severely impacted by either training or from grazing domestic animals. Even use by several individuals will have an impact on springs and seeps, so excluding vehicle traffic may not be sufficient.

The highest slopes and ridges of the YFC are either bare rock surfaces or rock pavement (soil overlain with a weathered surface of small rocks). If surfaces are undisturbed, there will be minimal erosion. However, even one pass of any training vehicle over such surfaces in wet weather causes significant impacts. Vegetation will be affected regardless of wet or dry conditions, and at such elevations and harsh climatic conditions, vegetation may take decades to re-colonize the disturbed area.

The cliffs of Selah Creek Canyon, Alkali Canyon, and the Columbia River provide unique habitats in the YFC area for raptors. These areas can be impacted during the nesting season by traffic either at the base of the cliffs (in the canyons) or along the tops near the cliff edge.

Recommendations

In general, vehicle use should be concentrated on resistant areas and during times when traffic causes the least damage. Location and timing of new activities should be planned giving consideration to soil, water, and biotic resources as well as training needs. Priorities on protecting natural resources should begin with the soil base and strongest efforts to preserve it, including, vehicle control, and maintenance and reestablishment of

vegetation. Vegetation loss should be reduced or avoided altogether, and a maximum number of vegetation layers maintained in order to preserve species richness and reduce wind and water erosion. Recommendations for specific areas are:

- a. Eliminate traffic in stream beds.
- b. Discontinue use of two fords on Squaw Creek (adjacent to sagegrouse lek) if the lek is still being used.
- c. Improve or harden all other designated fords.
- d. Prohibit crossing at non-designated sites.
- e. Improve major roads to control dust and erosion.
- f. Designate all springs, seeps, and ponds as off-limits.
- g. Designate rocky slopes and cliffs, especially in the Northeast along Alkali, Selah, and North Fork Squaw Creeks as off-limits.
- h. Expand current special use area around Borden Springs to include additional Columbia milk-vetch sites.
- i. Define leks and potential nesting areas with additional buffers and limit sagebrush control programs within that area.

PREFACE

Personnel of the US Army Engineer Waterways Experiment Station (WES) conducted the study described herein during the period February 1989 to September 1989 for the US Army Corps of Engineers, Seattle District, Washington, under Project No. E87-893153.

The study was conducted under the general supervision of Dr. W. F. Marcuson III, Chief, Geotechnical Laboratory (GL); Dr. J. Harrison, Chief, Environmental Laboratory (EL); MAJ Monte L. Pearson, Ph.D., Assistant to Chief, GL; Mr. N. R. Murphy, Chief, Mobility Systems Division (MSD), GL; Dr. A. G. Franklin, Chief, Earthquake Engineering and Geosciences Division (EEGD), GL; and Dr. C. J. Kirby, Chief, Environmental Resources Division (ERD), EL. The study was conducted under the direct supervision of Mr. R. P. Smith, Chief, Terrain Evaluation Branch (TEB), MSD; Dr. L. M. Smith, Chief, Engineering Geology Branch (EGB), EEGD; Mr. E. C. Brown, Chief, Wetlands and Terrestrial Habitat Group (WTHG), ERD; and Mr. H. R. Hamilton, Chief, Resource Analysis Group (RAG), ERD.

MAJ Pearson coordinated the overall study. Ms. R. M. Drinkard, TEB, MSD, Messrs. T. C. Dean, Modeling Branch, MSD, and G. B. McKinley and C. P. Rabalais, TEB, MSD, conducted the field data collection. Meses. S. J. Price and P. A. Morris, TEB, MSD, produced the mobility and maneuver damage predictions. Ms. M. Sabol, Hilton Systems, Inc., prepared the maps. Ms. Morris, TEB, MSD, and MAJ Pearson, GL, prepared Parts I through IV of this report. Mr. R. J. Larson, Chief, Geologic Environments Analysis Section (GEA), EGB, EEGD, prepared Part V of this report. Ms. L. J. O'Neil, and Mr. M. R. Waring, RAG, ERD, Dr. H. G. Hughes, and Dr. M. C. Landin, WTHG, ERD prepared Part VI of this report. Dr. Hughes is under an Intergovernmental Personnel Act Agreement between Pennsylvania State University, DuBois, PA, and RAG.

COL Larry B. Fulton, EN, was the Commander and Director during the conduct of this study and preparation of this report. Dr. Robert W. Whalin was Technical Director.

CONTENTS

	<u>Page</u>
EXECUTIVE SUMMARY.....	1
PREFACE.....	11
CONVERSION FACTORS, NON-SI TO SI (METRIC)	
UNITS OF MEASUREMENT.....	18
PART I: INTRODUCTION.....	19
Background.....	19
Objective.....	19
Scope.....	19
Definitions.....	20
PART II: STUDY VEHICLES, TERRAIN DATA, AND SURFACE CONDITIONS.....	23
Study Vehicles.....	23
Terrain Data.....	24
Surface Conditions.....	26
PART III: MOBILITY PREDICTIONS.....	28
AMM Mobility Performance.....	28
AMM Vehicle Characteristics.....	28
AMM Terrain Descriptions.....	28
Speed Performance.....	29
Factors Limiting Speed.....	29
PART IV: EFFECTS OF VEHICLE TRAFFIC ON STUDY AREA.....	30
Soil Disturbance Levels.....	30
Rut Depth Relations.....	30
Maneuver Areas.....	31
Effects of Vehicle Traffic.....	32
PART V: SOIL EROSION IMPACTS.....	41
Objective.....	41
Significance of Soil Erosion in Environmental Impact.....	41
Factors Influencing Soil Erosion.....	42
Purpose.....	43
Environmental Factors Influencing Erosion.....	45
Soil Erosion Processes.....	50
Estimation of Possible Soil Erosion Rates.....	57
Recommendations.....	63
PART VI: EFFECTS OF TRAFFIC IN SELECTED NATURAL RESOURCES.....	65
Background.....	65
Impact Assessment.....	83
Recommendations.....	99
REFERENCES.....	110

* PROPOSED 9TH INFANTRY DIVISION FORCE CONVERSION, MANEUVER DAMAGE,
EROSION, AND NATURAL RESOURCES ASSESSMENT, YAKIMA FIRING CENTER,
WASHINGTON: VOLUME II: PLATES..... *

* Published separately in Volume II.

LIST OF TABLES

<u>No.</u>		<u>Page</u>
1	Acres Affected by Soil Disturbance Level, Low Scenario (10 passes).....	66
2	Acres Affected by Soil Disturbance Level, Medium Scenario (50 passes).....	67
3	Acres Affected by Soil Disturbance Level, High Scenario (1,000 passes).....	68
4	Classification and Extent of Riparian Cover Types.....	69
5	Location of Seeps, Springs, and Ponds.....	71
6	Classification and Extent of Cover Types on the YFC.....	75
7	Biota of Special Interest, Reason for Interest, and Preferred Habitat.....	78
8	Location of Selected Plant and Wildlife Observations.....	80
9	Sage Grouse Lek Locations.....	82
10	Predicted Percent Loss of Vegetation and Soil Productivity by Soil Disturbance Category.....	86
11	Relative Impacts of Force Structure on Vegetation and Soil Productivity.....	88
12	Type and Extent of Riparian Erosion.....	90
13	Discontinuity of the Riparian Area.....	91
14	Occurrence of Various Activities.....	100

LIST OF FIGURES

<u>No.</u>		<u>Page</u>
1	Location of YFC study area.....	21
2	Ten pass soil disturbance level versus percent area for each force structure in the dry normal surface condition.....	33
3	Ten pass soil disturbance level versus percent area for each force structure in the wet-wet slippery surface condition.....	34
4	Fifty pass soil disturbance level versus percent area for each force structure in the dry normal surface condition...	35
5	Fifty pass soil disturbance level versus percent area for each force structure in the wet-wet slippery surface condition.....	36
6	One thousand pass soil disturbance level versus percent area for each force structure in the dry normal surface condition...	37
7	One thousand pass soil disturbance level versus percent area for each force structure in the wet-wet slippery surface condition.....	38

LIST OF PLATES*

<u>No.</u>	
1	Slope map for Yakima Firing Center study area
2	Spatial distribution of soil types for Yakima Firing Center study area
3	Speed map for M998 (HMMWV) wheeled vehicle in the dry normal surface condition

* All plates are found in Volume II.

LIST OF PLATES (Continued)

No.

- 4 Speed map for M998 (HMMWV) wheeled vehicle in the wet-wet slippery surface condition
- 5 Speed map for 8X8 wheeled combat vehicle in the dry normal surface condition
- 6 Speed map for 8X8 wheeled combat vehicle in the wet-wet slippery surface condition
- 7 Speed map for M60A3 combat tank in the dry normal surface condition
- 8 Speed map for M60A3 combat tank in the wet-wet slippery surface condition
- 9 Speed limiting reason map for M998 (HMMWV) wheeled vehicle in the dry normal surface condition
- 10 Speed limiting reason map for 8X8 wheeled combat vehicle in the dry normal surface condition
- 11 Speed limiting reason map for M60A3 combat tank in the dry normal surface condition
- 12 Speed limiting reason map for M998 (HMMWV) wheeled vehicle in the wet-wet slippery surface condition
- 13 Speed limiting reason map for 8X8 wheeled combat vehicle in the wet-wet slippery surface condition
- 14 Speed limiting reason map for M60A3 combat tank in the wet-wet slippery surface condition
- 15 Ten pass soil disturbance level map for 3-3-5 and 4-3-3 (HMMWV) force structures in the dry normal surface condition
- 16 Fifty pass soil disturbance level map for 3-3-5 and 4-3-3 (HMMWV) force structures in the dry normal surface condition
- 17 One thousand pass soil disturbance level map for 3-3-5 and 4-3-3 (HMMWV) force structures in the dry normal surface condition
- 18 Ten pass soil disturbance level map for 3-3-5 and 4-3-3 (HMMWV) for structures in the wet-wet slippery surface condition
- 19 Fifty pass soil disturbance level map for 3-3-5 and 4-3-3 (HMMWV) force structures in the wet-wet slippery surface condition
- 20 One thousand pass soil disturbance level map for 3-3-5 and 4-3-3 (HMMWV) force structures in the wet-wet slippery surface condition
- 21 Ten pass soil disturbance level map for the 4-3-3 (8X8) force structure in the dry normal surface condition
- 22 Fifty pass soil disturbance level map for the 4-3-3 (8X8) force structure in the dry normal surface condition
- 23 One thousand pass soil disturbance level map for the 4-3-3 (8X8) force structure in the dry normal surface condition
- 24 Ten pass soil disturbance level map for the 4-3-3 (8X8) force structure in the wet-wet slippery surface condition
- 25 Fifty pass soil disturbance level map for the 4-3-3 (8X8) force structure in the wet-wet slippery surface condition
- 26 One thousand pass soil disturbance level map for the 4-3-3 (8X8) force structure in the wet-wet slippery surface condition

LIST OF PLATES (Continued)

No.

- 27 Ten pass soil disturbance level map for the 5-5-0 force structure in the dry normal surface condition
- 28 Fifty pass soil disturbance level map for the 5-5-0 force structure in the dry normal surface condition
- 29 One thousand pass soil disturbance level map for the 5-5-0 force structure in the dry normal surface condition
- 30 Ten pass soil disturbance level map for the 5-5-0 force structure in the wet-wet slippery surface condition
- 31 Fifty pass soil disturbance level map for the 5-5-0 force structure in the wet-wet slippery surface condition
- 32 One thousand pass soil disturbance level map for the 5-5-0 force structure in the wet-wet slippery surface condition
- 33 Rate of soil erosion for 3-3-5 and 4-3-3 (HMMWV) force structures in the dry normal surface condition for ten passes
- 34 Rate of soil erosion for 3-3-5 and 4-3-3 (HMMWV) force structures in the dry normal surface condition for fifty passes
- 35 Rate of soil erosion for 3-3-5 and 4-3-3 (HMMWV) force structures in the dry normal surface condition for one thousand passes
- 36 Rate of soil erosion for 3-3-5 and 4-3-3 (HMMWV) force structures in the wet-wet slippery surface condition for ten passes
- 37 Rate of soil erosion for 3-3-5 and 4-3-3 (HMMWV) force structures in the wet-wet slippery surface condition for fifty passes
- 38 Rate of soil erosion for 3-3-5 and 4-3-3 (HMMWV) force structures in the wet-wet slippery surface condition for one thousand passes
- 39 Rate of soil erosion for the 4-3-3 (8X8) force structure in the dry normal surface condition for ten passes
- 40 Rate of soil erosion for the 4-3-3 (8X8) force structure in the dry normal surface condition for fifty passes
- 41 Rate of soil erosion for the 4-3-3 (8X8) force structure in the dry normal surface condition for one thousand passes
- 42 Rate of soil erosion for the 4-3-3 (8X8) force structure in the wet-wet slippery surface condition for ten passes
- 43 Rate of soil erosion for the 4-3-3 (8X8) force structure in the wet-wet slippery surface condition for fifty passes
- 44 Rate of soil erosion for the 4-3-3 (8X8) force structure in the wet-wet slippery surface condition for one thousand passes
- 45 Rate of soil erosion for the 5-5-0 force structure in the dry normal surface condition for ten passes
- 46 Rate of soil erosion for the 5-5-0 force structure in the dry normal surface condition for fifty passes
- 47 Rate of soil erosion for the 5-5-0 force structure in the dry normal surface condition for one thousand passes

LIST OF PLATES (Concluded)

No.

- 48 Rate of soil erosion for the 5-5-0 force structure in the wet-wet slippery surface condition for ten passes
- 49 Rate of soil erosion for the 5-5-0 force structure in the wet-wet slippery surface condition for fifty passes
- 50 Rate of soil erosion for the 5-5-0 force structure in the wet-wet slippery surface condition for one thousand passes
- 51 Soil erosion severity for 3-3-5 and 4-3-3 (HMMWV) force structures for ten passes
- 52 Soil erosion severity for 3-3-5 and 4-3-3 (HMMWV) force structures for fifty passes
- 53 Soil erosion severity for 3-3-5 and 4-3-3 (HMMWV) force structures for one thousand passes
- 54 Soil erosion severity for 4-3-3 (8X8) force structure for ten passes
- 55 Soil erosion severity for the 4-3-3 (8X8) force structure for fifty passes
- 56 Soil erosion severity for the 4-3-3 (8X8) force structure for one thousand passes
- 57 Soil erosion severity for the 5-5-0 force structure for ten passes
- 58 Soil erosion severity for the 5-5-0 force structure for fifty passes
- 59 Soil erosion severity for 5-5-0 force structure for one thousand passes
- 60 Riparian zone classifications
- 61 Special features - natural
- 62 LANDSAT classifications (vegetation associations)
- 63 Special features - military
- 64 Riparian zone - categories of erosion

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI*
(metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
acres	0.404686	hectares
acres	4,046.873	square metres
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins**
feet	0.3048	metres
inches	2.54	centimetres
knots (international)	0.514444	metres per second
miles (US statute)	1.609347	kilometres
miles (US statute) per hour	0.44704	metres per second
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
square inches	6.4516	square centimetres
tons (force)	8.896444	kilonewtons

* SI refers to the international system of units which is the metric system being adopted in the United States. Conversion factors are taken from ASTM Designation: E380-85, Standard for Metric Practice, issued in October 1985. SI literally stands for *Le Système International d'Unités*.

** To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

PROPOSED 9TH INFANTRY DIVISION FORCE CONVERSION, MANEUVER
DAMAGE, EROSION, AND NATURAL RESOURCES ASSESSMENT
YAKIMA FIRING CENTER, WASHINGTON

VOLUME I: MAIN TEXT

PART I: INTRODUCTION

Background

1. Personnel at the US Army Corps of Engineers, Seattle District (CENPS) asked the US Army Engineer Waterways Experiment Station (WES) to determine the impact of a conversion from a motorized to a mechanized force structure on Yakima Firing Center (YFC), WA. Specifically WES was asked to (a) provide an assessment of vehicle mobility and maneuver damage, (b) determine erosion effects, (c) provide an assessment of the environmental impact of maneuver damage, and (d) make recommendations for management and mitigation. These would address four force structures related to the possible 9th Inventory Division Motorized (9ID MTZ), I Corps mechanization.

Objective

2. The objective of this study was to provide mobility, maneuver damage, and environmental analyses to determine the impact of the current and/or alternative force structures on the present land (263,131 acres*, Department of the Army 1978) owned by the Army at YFC. Note that the area of potential traffic for the YFC study area is equal to the total study acreage minus the acreage consisting of urban, off-limits, and water areas (24,734 acres).

Scope

3. The principal activities necessary to achieve the objective of this study were as follows:

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 18.

- a. The Army Mobility Model (AMM), as described in the High Mobility (HIMO) study (Nuttall and Randolph 1976), and a digital terrain data base for the study area were used to predict maneuver damage based on the sinkage of the vehicles and the effect of soil disturbance due to tire and track slip and turning. Relationships were developed to predict soil disturbance levels as a function of the soil strength and the number of vehicle passes for the study vehicles and surface conditions in the study area.
- b. Climatological, soil, geologic, topographic, hydrologic, and vehicular damage data were used to interpret soil erosion effects.
- c. Soil, slope, erosion, vegetation, hydrologic, and wildlife data were used to produce a natural resource assessment of maneuver damage addressing the four proposed force structures.

4. This report describes the methodology, discusses the various predictive models, presents mobility and natural resources data, and discusses impacts on the study area. Figures located in Volume I are referred to in the text as such. Oversized maps are located in Volume II and are referred to in the text as plates. The YFC study area is located in Kittitas and Yakima Counties, WA (Figure 1) and is a subinstallation of Fort Lewis, WA.

Definitions

5. The following are definitions of terms:

- a. Cone index (CI). An index of the shearing resistance of a medium obtained with a standard cone penetrometer.
- b. Remolding index (RI). A ratio in terms of CI that expresses the proportion of the original strength of a soil that will be retained after being altered by the traffic of a moving vehicle.
- c. Rating cone index (RCI). The product of the RI and the average of the measured in situ CI for a specific layer of soil (usually 0 to 6 in.).
- d. Vehicle cone index (VCI). The minimum RCI that will permit a vehicle to complete a specified number of passes. For example, VCI_{50} means the minimum RCI needed to complete 50 passes, and VCI_1 means the minimum RCI needed to complete one pass.
- e. Off-road. The vehicle is off-road when it is operating cross-country or is not negotiating a specific path.
- f. Areal terrain. Terrain features (usually off-road) that are depicted as polygons on a map as opposed to features such as roads that are depicted as lines.
- g. Soil disturbance level. The soil surface surrounding a track or rut that has been displaced, compacted, or has lost strength due to remolding.

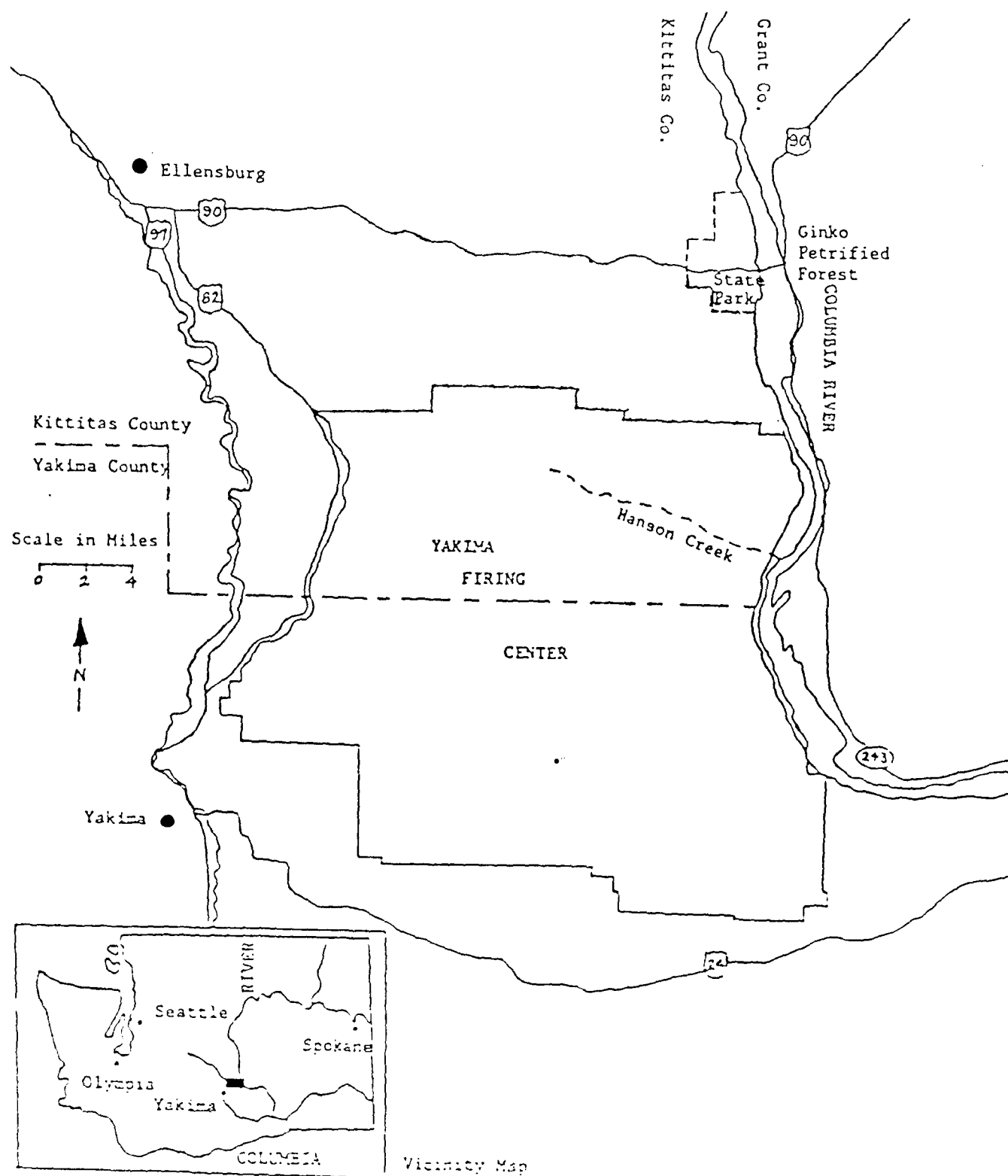


Figure 1. Location of YFC study area

- h. Liquid limit. The moisture content at which a pat of soil in a standard brass cup and cut by a groove of standard dimensions will flow together so as to close the groove 1/2 in. along its bottom under the impact of 25 blows in a standard liquid limit apparatus.
- i. Deflation. The sorting out, lifting, and removal of loose dry fine-grained particles (usually clay and silt sizes) by the turbulent eddy action of the wind.
- j. Abrasion. The mechanical wearing, grinding, scraping, or rubbing away of rock surfaces by friction and impact, in which the solid rock particles transported by wind are the tools of abrasion. The term corrasion is essentially synonymous.
- k. Transport. A phase of sedimentation that includes the movement by natural agents (wind) of sediment or of any loose material, either as solid particles or in solution, from one place to another on or near the earth surface.
- l. Erosion. The general process or the group of processes whereby the materials of the earth's crust are loosened, dissolved, or worn away, by natural agencies, which include weathering, solution, corrasion, and transportation (exclusive of mass wasting such as landslides, slump, etc.).
- m. Environmental NOGO. Areas recommended to be placed off-limits to vehicles by administrative order, based on the special or sensitive nature of the area.
- n. Soil Disturbance NOGO. A soil disturbance NOGO situation is predicted when a vehicle is immobilized by sinkage to its ground clearance during multiple passes in the same rut. The reasons for soil disturbance NOGO are insufficient soil strength, insufficient traction, soil and slope resistances, and a combination of obstacle, soil, slope, and vegetation acting jointly.
- o. Wetness index. The influence of the water table on the wetness of the soil and its duration of wetness is measured in terms of a wetness index. The wetness index ranges from 0 (arid) to 5 (saturated, perennially waterlogged).

PART II: STUDY VEHICLES, TERRAIN DATA, AND SURFACE CONDITIONS

Study Vehicles

6. Representative vehicles for the armored, mechanized, and motorized divisions were chosen for evaluation. They were the M60A3/M1, M113A1/M2, and the M998 (HMMWV) and the 8X8 wheeled combat vehicle, respectively. Additionally, other types of vehicles will also be maneuvering the study area. Two factors considered in the determination of the principal vehicle for each vehicle force structure were a statistical analysis of the number of vehicles and the total number of miles that the vehicles would travel during a training exercise. In general, wheeled vehicles travel a greater number of miles during a training exercise than tracked vehicles. Soil disturbance (i.e., rut depth) maps for the representative vehicles and surface conditions were prepared for each force structure for a varied number of vehicle passes. In most cases, the wheeled or tracked vehicle which exhibited the greatest level of disturbance for each force structure was chosen as the principal vehicle to represent maneuver damage. However, in some cases, the respective wheeled vehicle was chosen as the principal vehicle in spite of the fact that it may not have caused as much damage to the study area as the tracked vehicle does per unit of movement, but would have a greater maneuver impact simply because it traveled more miles in a training exercise. The principal maneuver vehicles selected for evaluation purposes from each vehicle force structure were:

Force Structure*	Representative Vehicle	Principal Vehicle Characteristics for Force Structure	
		Principal Vehicle	Contact** Pressure psi
3 Armored	M60A3	M998, High Mobility	27.1
3 Mechanized	M113A1/M2	Multi-purpose Wheeled	
5 Motorized	HMMWV	Vehicle (HMMWV), 8,860 lb	

(Continued)

* These data are provided by I Corps personnel and refer to the number and type of maneuver battalions.

** As a comparison, an average 6 ft tall human male exerts approximately 2 psi.

Principal Vehicle Characteristics for Force Structure			
Force Structure*	Representative Vehicle	Principal Vehicle	Contact Pressure psi
4 Armored	M60A3/M1	M998, High Mobility	27.1
3 Mechanized	M113A1/M2	Multi-purpose Wheeled	
3 Motorized	HMMWV	Vehicle (HMMWV)† 8,860 lb	
4 Armored	M60A3/M1	8X8 Wheeled	45.4
3 Mechanized	M113A1/M2	Combat Vehicle††,	
3 Motorized	HMMWV	27,660 lb	
5 Armored	M60A3/M1	M60A3, Combat Tank	13.3
5 Mechanized	M113A1/M2	127,000 lb	
0 Motorized	HMMWV		

† Future direction from I Corps personnel may direct WES to analyze this force structure with the M113A1 as the principal vehicle.

†† The 8X8 wheeled combat vehicle required as principal vehicle under guidance of FORSCOM personnel.

Terrain Data

7. Personnel from the WES collected ground measured data at the study area. An extremely important aspect of any field data collection program is the selection of sites to be studied and documented. Preliminary site selections were made using aerial photographs and standard class 1:50,000 scale topographic maps. Each site chosen was representative of the terrain surrounding it. Sites selected were finalized after the conduct of a thorough ground reconnaissance. Data were eventually collected from 43 ground sites throughout the study area. Observation sites were also established between ground sites so as to note any changes in terrain features and soil type. Many sections of the YFC study area are analogous with respect to terrain features and were classed as such. Factor maps were drawn from evaluation and analysis of the measured ground truth data. Factor maps for soils, obstacles, drainage, vegetation, and elevation contour (slope) data were prepared. Plate 1 shows the slope map for the YFC study area.

Soil types

8. The US Army Engineer Waterways Experiment station (1960) describes and explains the use of the Unified Soil Classification System (USCS). The following are descriptions of the soil types (classified by USCS) found in the

YFC study area. Plate 2* is a map which provides the spatial distribution of soil types identified in the YFC study area. Bulk samples were taken and tested for moisture content and grain size distribution.

9. GP soil type. This group comprises poorly graded gravel containing little or no nonplastic fines (less than 5 percent passing the No. 200 sieve). This group was found in 40.4 percent of the study area.

10. ML soil type. This group consists of sandy silts, clayey silts, or inorganic silts with relatively low plasticity. Also included are loess-type soils and rock flours. These soils have a low liquid limit (less than 50). This group was found in 25.7 percent of the study area.

11. GM soil type. This group comprises gravel with fines (more than 12 percent passing the No. 200 sieve) having low or no plasticity. The gradation of the materials is not considered significant and both well-graded and poorly graded materials are included. Some of the gravel in this group will have a binder composed of natural cementing agents so proportioned that the mixture shows negligible swelling or shrinkage. Thus, the dry strength of such materials is provided by a small amount of soil binder. The fine fraction of other materials in this group may be composed of silts or rock flour types having little or no plasticity, and the mixture will exhibit no dry strength. This group was found in 23.9 percent of the study area.

12. CLML soil type. This is an example of a borderline soil which exhibits characteristics of both CL and ML soil groups. The CL soil group comprises clays with low plasticity (liquid limit less than 50). This ML group comprises silts with low plasticity. This group was found in 6.0 percent of the study area.

13. SM soil type. This group comprises sands with fines (more than 12 percent passing the No. 200 sieve) having low or no plasticity. This group was found in 0.9 percent of the study area.

14. CL soil type. In this group, the symbol C stands for clay with L denoting a low liquid limit (less than 50). The soils are primarily inorganic clays. Low plasticity clays are usually lean clays, sandy clays, or silty clays. This group was found in 0.4 percent of the study area.

15. GC soil type. This group comprises gravel soils with fines (more than 12 percent passing the No. 200 sieve) which may or may not exhibit

* All plates are found in Volume II.

plasticity. The gradation of the materials is not considered significant and both well-graded and poorly graded materials are included. The plasticity of the binder fraction has more influence on the behavior of the soils than does the variation in gradation. The fine fraction is generally composed of clays. This group was found in 0.4 percent of the study area.

16. Rock. A small amount of rock (2.4 percent) was also found in the YFC study area.

Obstacles, vegetation and elevation data

17. Obstacles. Obstacles observed during data collection consisted of escarpments, embankments, and rock outcrops.

18. Vegetation. Areas of vegetation observed during data collection consisted of scrubs, grassland, and scattered trees. More specific vegetation information was collected for the natural resources evaluation (refer to Part VI).

19. Elevation data. A 1:50,000 scale map was prepared from elevation contour data obtained from a Yakima Firing Center Special Map drawn partially by WES and the Defense Mapping Agency. These data were used for slope determination.

Surface Conditions

20. The two surface conditions considered for analysis were dry normal and wet-wet slippery.

- a. Dry normal condition. The dry normal surface condition describes the lowest soil moisture condition for each soil type which in turn produces the highest soil strengths found during the driest 30-day period for an average rainfall year. It has been at least 6 hr since the last rainfall. This is typically the best surface condition.
- b. Wet-wet slippery condition. The wet-wet slippery surface condition describes the highest soil moisture and associated reduced soil strength found during the wettest 10-day period for a year having 150 percent of average rainfall. It has rained within the last 6 hr which produces a slippery effect that reduces vehicle traction. Some sinkage occurs because of softer soil conditions. For the YFC study area, this condition may have a maximum occurrence of 20 percent of the year. This is the worst case probability statistic which will only occur during the winter rain and spring snowmelt periods. Under actual conditions, the dry normal surface condition has a

statistical value of occurrence greater than 80 percent and the wet-wet slippery surface condition occurs at some boundary value less than 20 percent. The conditions existing between dry normal and wet-wet slippery were not considered.

21. The following are the soil strength values corresponding to the dry normal and wet-wet slippery surface conditions. These values are derived from the Soil Moisture-Strength Prediction (SMSP) model (see paragraph 61) (Kennedy et al. 1988). The SMSP model uses precipitation data for an area to predict soil moisture content and soil strength values in terms of rating cone index (RCI) for each of the USCS soil type classes and for each wetness index. The wetness index for an area ranges from 0 (arid) to 5 (saturated, perennially waterlogged) and may be inferred from the slope and vegetation type. Lower slope values are assigned a higher wetness index. Additionally, vegetation types which indicate marsh, swamps, or wetlands are assigned a wetness index of five, while a wet crop is assigned a wetness index of four.

<u>RCI</u>	<u>Percent of Total Study Area</u>	
	<u>Dry Normal</u>	<u>Wet-Wet Slippery</u>
>280	100.0	3.1
>220-280	0	4.4
>160-220	0	91.6
>100-160	0	0.9
>60-100	0	0
>40-60	0	0
>33-40	0	0
>26-33	0	0
>17-26	0	0
>11-17	0	0
≤11	0	0
Total	100.0	100.0

PART III: MOBILITY PREDICTIONS

AMM Mobility Performance

22. The AMM was used to predict off-road performances for the study vehicles for the dry normal and wet-wet slippery surface conditions in the study area. The AMM examines vehicle-driver-terrain interactions to determine the maximum feasible speed that a vehicle can achieve in a single areal terrain patch. The inputs to the AMM are vehicle characteristics and a quantitative terrain description of the study area.

AMM Vehicle Characteristics

23. The vehicle is specified in the data base in terms of geometric, inertial, and mechanical characteristics that determine its interactions with the terrain. The completed vehicle characterization as used by the model includes measures of dynamic response to ground roughness and to obstacle impact. The model structure permits use at these points of appropriate data derived either from actual field tests* or from supporting stand-alone computer simulation. The require steady-state tractive force-speed relation may also be input directly from field test data, when available, or computed using a power train submodule.*

AMM Terrain Descriptions

24. In the AMM, the basic approach to representing a complex terrain is to subdivide it into areal patches, generically referred to as terrain units, each of which can be considered uniform within its bounds. This concept is implemented by dividing the range of each individual terrain factor into a number of class intervals, based on consideration of vehicle response sensitivity, practical intervals. based on consideration of vehicle response sensitivity, practical measurement accuracy, and mapping resolution problems. A new terrain unit is defined whenever one or more factors fall into a new class

* Denotes use in this study.

interval. Each terrain unit is described by values for a series of 22 mathematically independent terrain factors for that unit.

Speed Performance

25. The output from the AMM is the maximum safe speed for a given study vehicle in each terrain unit examined. The output can be used to produce statistical analyses or can be displayed graphically as speed maps. The output selected for use in this study is the speed map.

26. The off-road speed map for a vehicle, terrain, and surface condition is a visual representation of the average speed the vehicle can sustain. The off-road speed map for the M998 (HMMWV) wheeled vehicle in the dry normal surface conditions (see paragraph 20) is shown in Plate 3. The off-road speed map for the M998 (HMMWV) wheeled vehicle in the wet-wet slippery surface condition is shown in Plate 4. The off-road speed map for the 8X8 wheeled combat vehicle in the dry normal surface condition is shown in Plate 5. The off-road speed map for the 8X8 wheeled combat vehicle in the wet-wet slippery surface condition is shown in Plate 6. The off-road speed map for the M60A3 tank in the dry normal surface condition is shown in Plate 7. The off-road speed map for the M60A3 tank in the wet-wet slippery surface condition is shown in Plate 8.

Factors Limiting Speed

27. Speed is limited by one or a combination of the following factors off-road:

- a. Traction available to overcome the combined resistances of soil, slope, obstacles, and vegetation.
- b. Driver discomfort in negotiating rough terrain (ride) and his tolerance to vegetation and obstacle impacts.
- c. Driver reluctance to proceed faster than the speed at which the vehicle could be braked to a stop within the visibility distance prevailing in the areal unit.
- d. Maneuvering to avoid trees and/or obstacles.
- e. Acceleration or deceleration between obstacles if they are to be overridden.

Plates 9 through 14 show the speed limiting reasons over the study area for each principal vehicle and surface condition.

PART IV: EFFECTS OF VEHICLE TRAFFIC ON STUDY AREA

Soil Disturbance Levels

28. Soil disturbance is defined as the soil surface surrounding a track or rut that has been displaced, compacted, or has lost strength due to remolding caused by vehicle traffic. For this study, the soil disturbance levels relate to rut depths resulting from vehicle traffic. Soil disturbance levels and corresponding rut depths for this study are:

<u>Soil Disturbance Levels</u>	<u>Rut Depths</u>
Minimal	0 to 0.5 in.
Slight	0.5 to 2 in.
Moderate	2 to 5 in.
High	5 to 12 in.
Severe	>12 in.

Soil disturbance levels were established from relations of rut depth as a function of vehicle passes, VCI, RCI, and vehicle characteristics. These soil disturbance level classes are arbitrary and are left to the discretion of the range conservation officer or appropriate land manager to modify as needed for a particular environment.

Rut Depth Relations

29. The fundamental relations of single tire sinkage on the first pass as a function of vehicle parameters such as the tire height, width, diameter, and deflection, and soil strength, wheel load, and slip were determined empirically from controlled laboratory tests in fine-grained soils and remoldable sands (Freitag 1965). These relations were modified based on several field test programs that required a detailed assessment and update of predictive relationships for vehicle traction, motion resistance, and sinkage. One-pass wheeled vehicle rut depth versus soil strength (RCI) relations were obtained by substituting specific study vehicle parameters at a constant slip value of 20 percent. Studies have indicated that 20 percent wheel slip for most vehicles in fine-grained soils is the point of maximum drawbar horsepower efficiency (or vehicle work output index). The vehicle's ground clearance was used as the maximum wheel sinkage because a vehicle operating in soft soils

will generally immobilize when its undercarriage drags on the soil surface. The relations were expanded to include a single track where the first pass sinkage was a function of track width, length, and soil strength (Turnage 1973). The relations were further adjusted based on vehicle tests and VCI_1 data.* This led to the development of the present first pass rut depth versus soil strength (RCI) relations for wheeled and tracked vehicles traveling in a straight path.

30. These first pass relations were used as a basis along with VCI_{50} data** and some 50 and limited 500 pass test results to establish multi-passes (i.e., in the same rut) relations. Additional methodology was developed from limited field data for adjusting these relations to account for terrain, slope, and vehicle steering influences (turning for wheeled vehicles and pivoting for tracked vehicles). These data indicated that wheeled and tracked vehicles produced rut depths on slopes and when turning/pivoting which corresponded to those described for straight-line travel, but at RCI values less than actual values used in the straight-line relationships (Willoughby and Turnage in preparation). Finally, the first pass relations, multipass relations, and adjustments to account for terrain, slope, and vehicle steering (turning for wheeled vehicles and pivoting for tracked vehicles) were used with the AMM to provide a model to predict soil disturbance due to vehicle traffic over an area. The model does not consider soil compaction below the soil disturbance depth nor does it consider the reduction of rock fragments by increased vehicle passes.

Maneuver Areas

31. No distinguishable maneuver corridors were established for the study area based on guidance from 9ID training personnel. Mobility NOGO's in the YFC study area were primarily associated with obstacles such as escarpments and steep slopes on embankments. Due to the high percentage of slopes

* VCI_1 values for the HMMWV, 8X8 wheeled combat vehicle, and M60A3 tank are 20, 29, and 20, respectively.

** VCI_{50} values for the HMMWV, 8X8 wheeled combat vehicle, and M60A3 tank are 45, 65, and 50, respectively. VCI_{50} is calculated from the WES VCI model which is described in the Analysis of Ground Mobility Models (ANNAMOB) study (Rula and Nuttall, 1971). This model is empirical and based on field tests.

(Plate 1) at the YFC less than 20 percent (71 percent), maneuverability as possible over the entire area (excluding urban, off-limits, and water areas) except that which was physically impossible to maneuver by the vehicles.

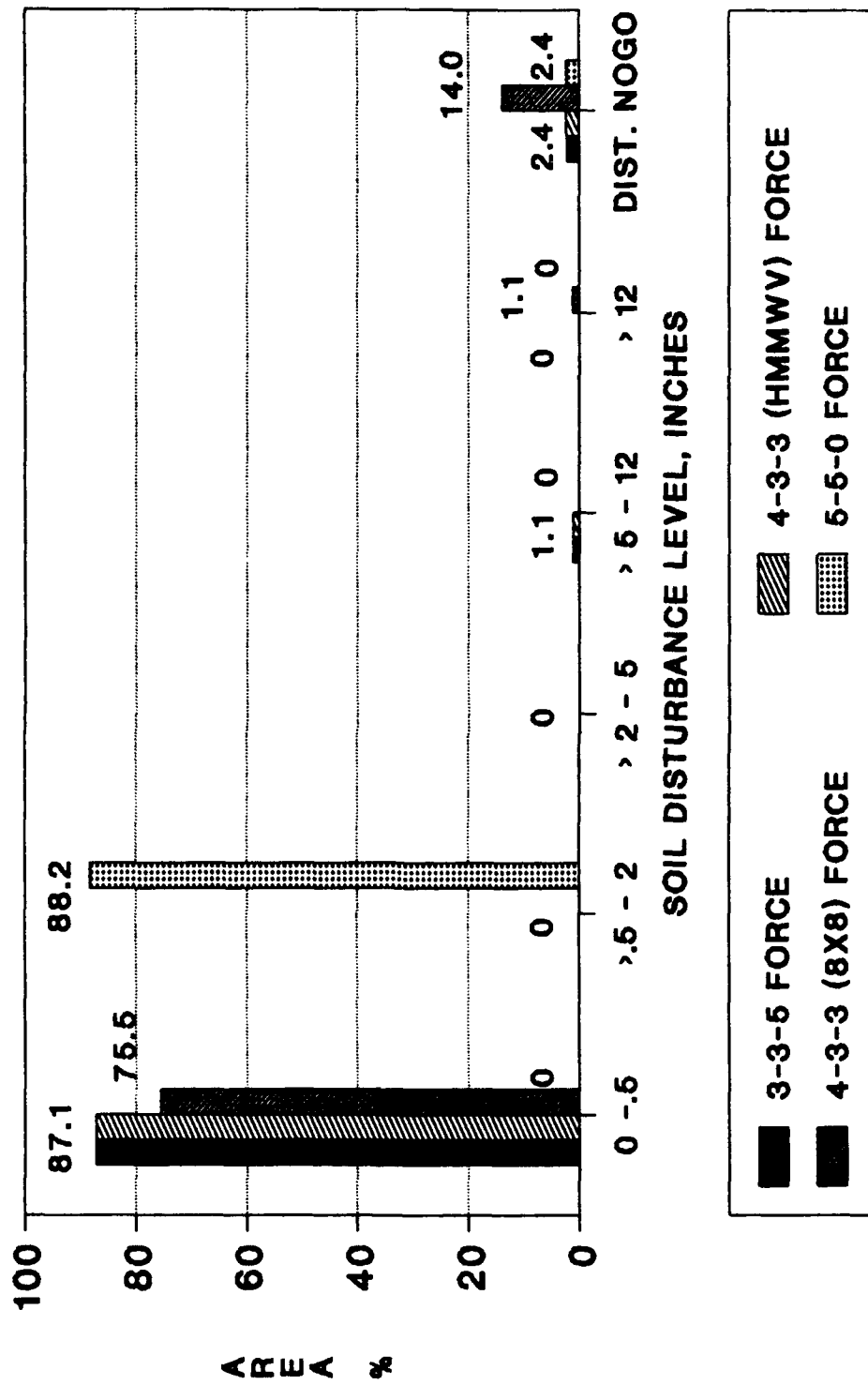
Effects of Vehicle Traffic

32. It was determined that 10, 50, and 1,000 vehicle passes over the entire terrain of the potential traffic area presented the best estimate of the low, medium, and high tactical scenarios, respectively. In general, a higher number of vehicle passes results in a higher level of disturbance (i.e., deeper rut depths) until the ground clearance of the vehicle is reached. This situation, however, does not occur in a linear fashion. Ten, 50, and 1,000 vehicle passes represent threshold values where a rate change in vehicle passes versus rut depth occurs.

33. Plates 15 through 32 show the soil disturbance maps for the calculated number of passes, for each vehicle force structure, and for surface condition. Note that the principal vehicle for the 3-3-5 and 4-3-3 vehicle force structure is the same (i.e., M998 HMMWV); therefore, Plates 15 through 20 are representative of both of these force structures. Plates 21 through 26 are representative of the 4-3-3 vehicle force structure only with the 8X8 wheeled combat vehicle as the principal vehicle. Plates 27 through 32 are representative of the 5-5-0 vehicle force structure only with the M60A3 tank as the principal vehicle. Figures 2 through 7 summarize the data graphically for detailed analysis. Note that in Figures 2 through 7, "DIST. NOGO" refers to the percentage of soil disturbance NOGO. In the YFC study area, the percentage of urban//off-limits area is for 9.4 percent. The percentage of open water is 0.0 percent. The chart values plus the percentage of urban/off-limits and open water area values equal 100 percent.

34. The following is an analysis of soil disturbance levels for 10, 50, and 1,000 vehicle passes, respectively. In the following discussion, soil disturbance NOGO's, urban, off-limits, and open water areas are not included (see Figures 2 through 7) because for training purposes they would not be maneuvered.

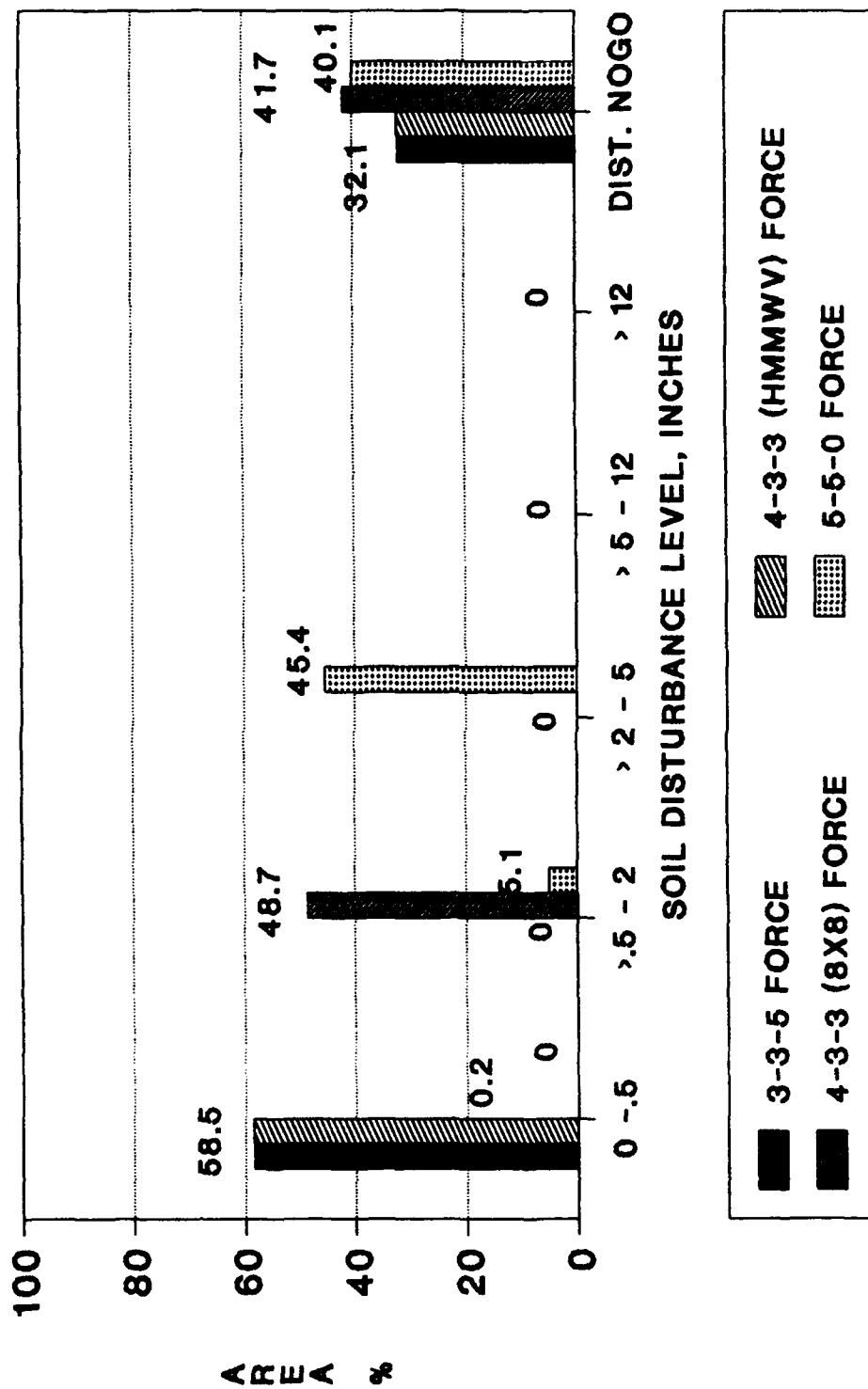
SOIL DISTURBANCE LEVEL VERSUS AREA* 10 PASSES DRY NORMAL



*URBAN/OFF-LIMITS + WATER=9.4% OF AREA

Figure 2. Ten pass soil disturbance level versus percent area for each force structure in the dry normal surface condition

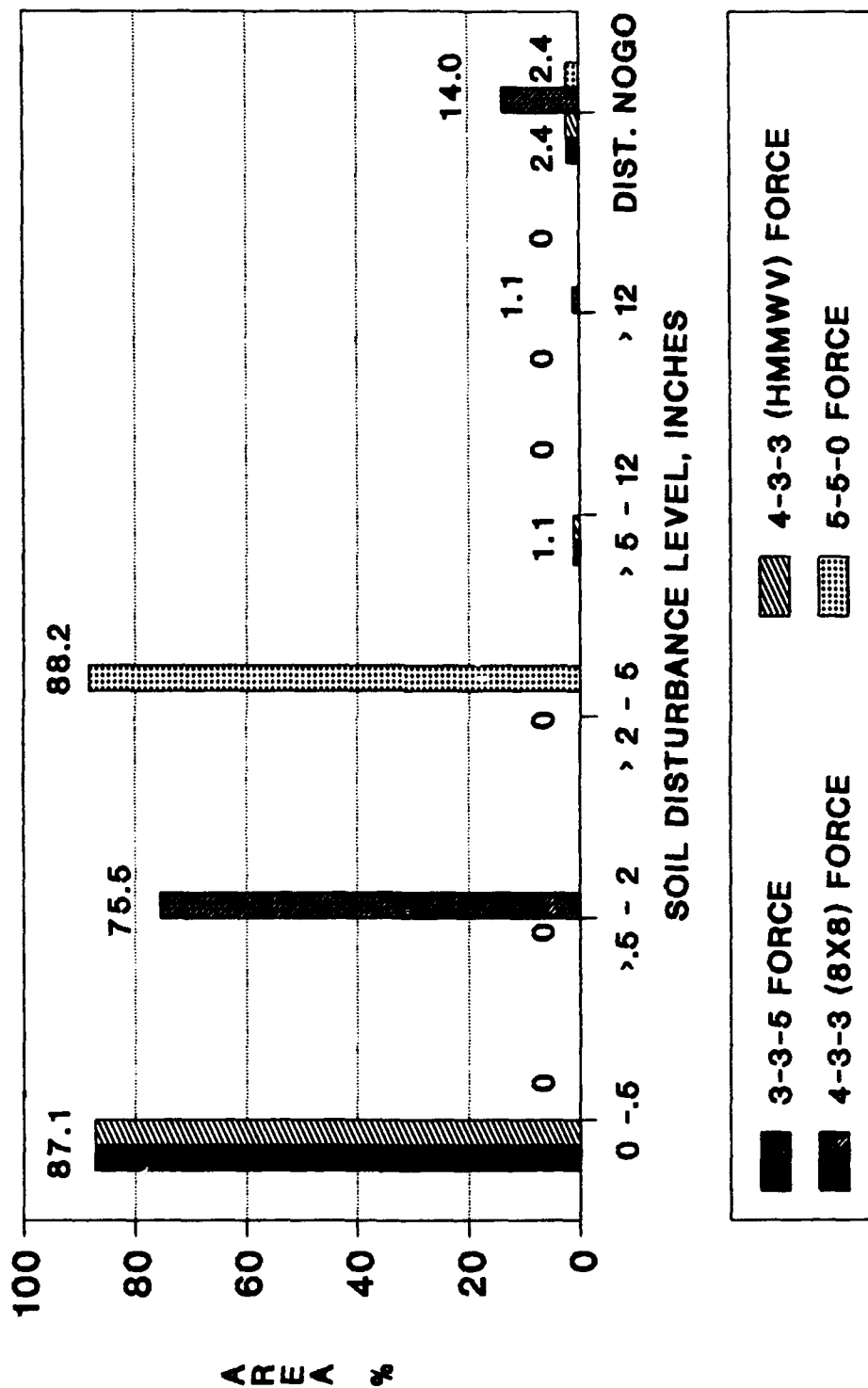
SOIL DISTURBANCE LEVEL VERSUS AREA* 10 PASSES WET/WET SLIPPERY



•URBAN/OFF-LIMITS + WATER-9.4% OF AREA

Figure 3. Ten pass soil disturbance level versus percent area for each force structure in the wet-wet slippery surface condition

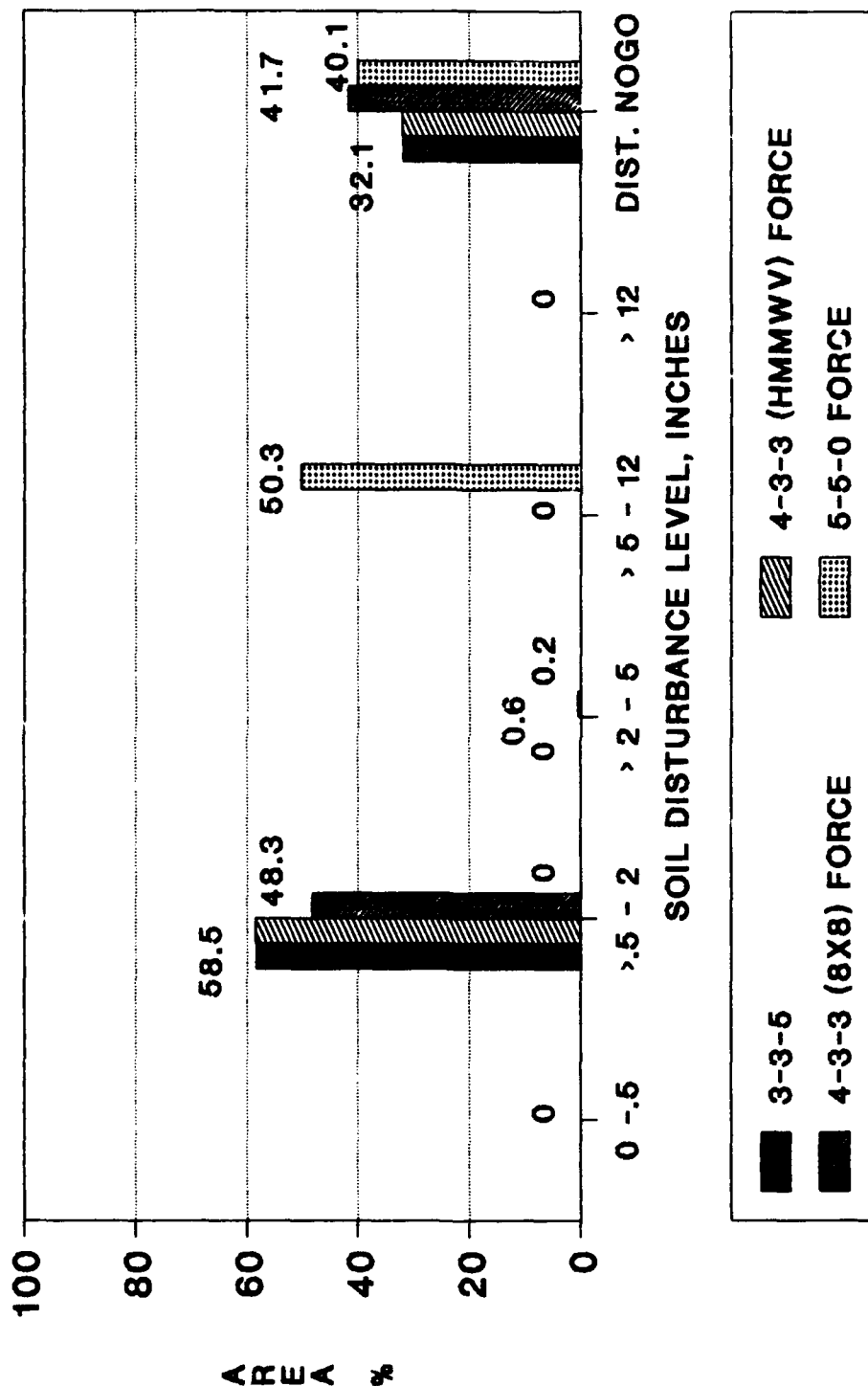
SOIL DISTURBANCE LEVEL VERSUS AREA* 50 PASSES DRY NORMAL



*URBAN/OFF-LIMITS + WATER-9.4% OF AREA

Figure 4. Fifty pass soil disturbance level versus percent area for each force structure in the dry normal condition

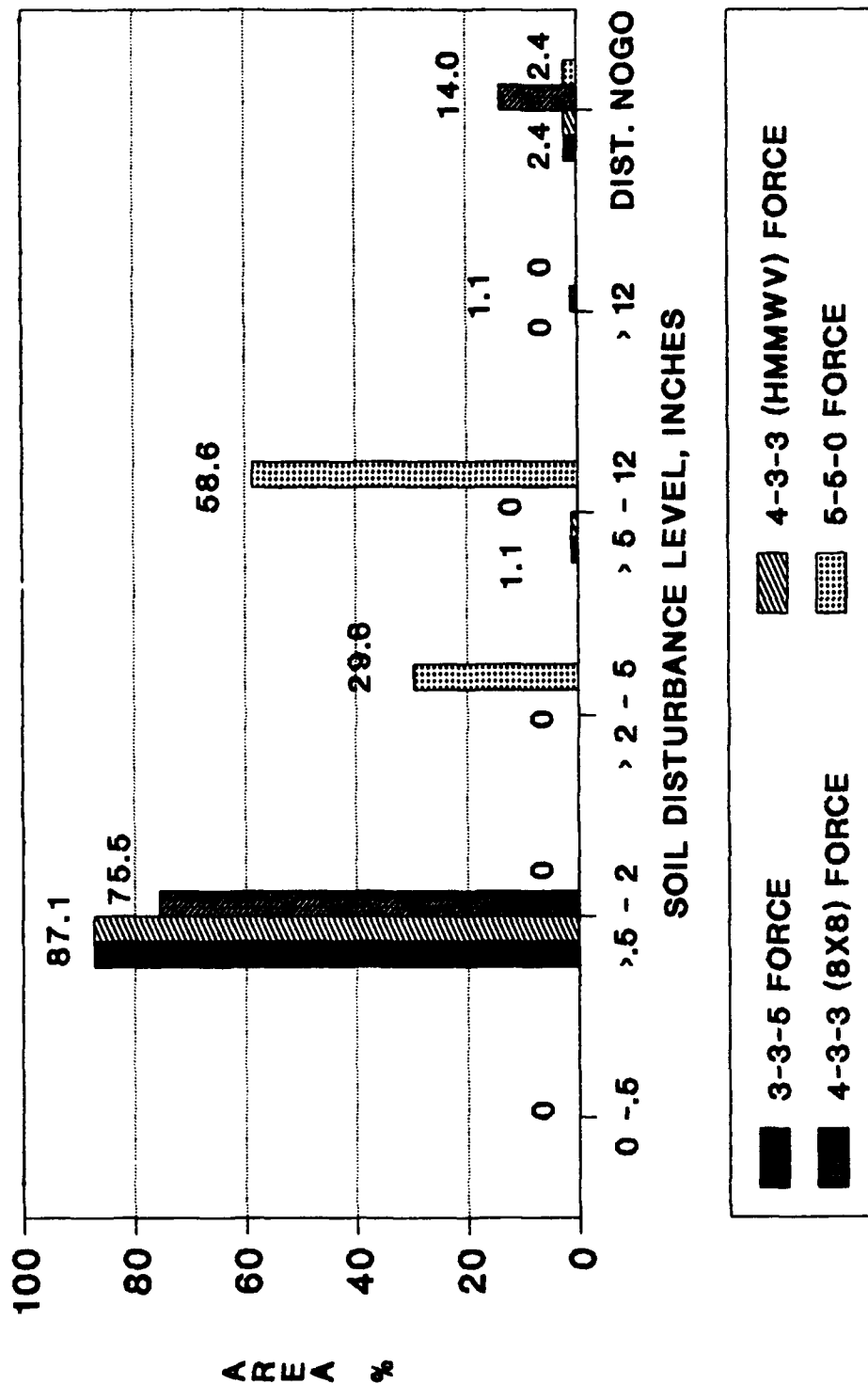
SOIL DISTURBANCE LEVEL VERSUS AREA* 50 PASSES WET/WET SLIPPERY



*URBAN/OFF-LIMITS + WATER-9.4% OF AREA

Figure 5. Fifty pass soil disturbance level versus percent area for each force structure in the wet-wet slippery surface condition

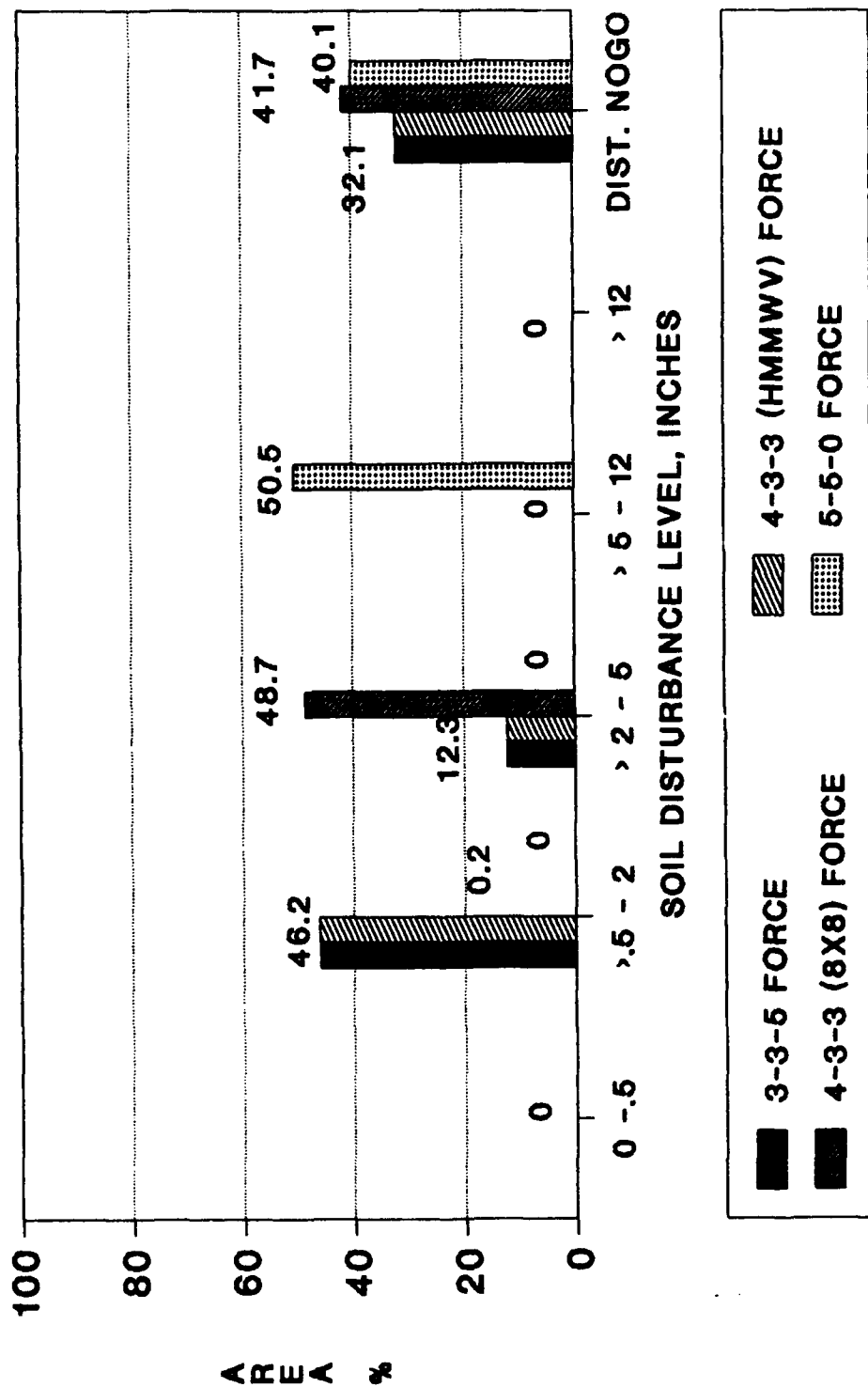
SOIL DISTURBANCE LEVEL VERSUS AREA* 1000 PASSES DRY NORMAL



*URBAN/OFF-LIMITS + WATER-9.4% OF AREA

Figure 6. One thousand pass soil disturbance level versus percent area for each force structure in the dry normal surface condition

SOIL DISTURBANCE LEVEL VERSUS AREA* 1000 PASSES WET/WET SLIPPERY



•URBAN/OFF-LIMITS + WATER-9.4% OF AREA

Figure 7. One thousand pass soil disturbance level versus percent area for each force structure in the wet-wet slippery surface condition

10 Passes

35. For the 3-3-5 and 4-3-3 (HMMWV) vehicle force structures, over 80 percent of the soil disturbance occurred in the 0- to 1/2-in. class with approximately 1 percent of the soil disturbance occurring in the 5- to 12-in. class for the dry normal surface condition. In the wet-wet slippery surface condition, approximately 59 percent of the soil disturbance occurred in the 0- to 1/2-in. class. For the 4-3-3 (8X8) vehicle force structure, approximately 76 percent of the soil disturbance occurred in the 0- to 1/2-in. class with approximately 1 percent of the soil disturbance occurring in the >12-in. class for the dry normal surface condition. In the wet-wet slippery surface condition, approximately 49 percent of the soil disturbance occurred in the 1/2- to 2-in. class with less than 1 percent of the soil disturbance occurring in the 0- to 1/2-in. class. For the 5-5-0 vehicle force structure, over 80 percent of the soil disturbance occurred in the 1/2- to 2-in. class in the dry normal surface condition. In the wet-wet slippery surface condition, over 40 percent of the soil disturbance occurred in the 2- to 5-in. class with approximately 5 percent of the soil disturbance occurring in the 1/2- to 2-in. class.

50 Passes

36. For the 3-3-5, and 4-3-3 (HMMWV) vehicle force structures, over 80 percent of the soil disturbance occurred in the 0- to 1/2-in. class with approximately 1 percent of the soil disturbance occurring in the 5- to 12-in. class in the dry normal surface condition. In the wet-wet slippery surface condition, 59 percent of the soil disturbance occurred in the 1/2- to 2-in. class. For the 4-3-3 (8X8) vehicle force structure, approximately 76 percent of the soil disturbance occurred in the 1/2- to 2-in. class with approximately 1 percent of the soil disturbance occurring in the >12-in. class in the dry normal surface condition. In the wet-wet slippery surface condition, 48 percent of the soil disturbance occurred in the 1/2- to 2-in. class with less than 1 percent of the soil disturbance occurring in the 2- to 5-in. class. For the 5-5-0 vehicle force structure, over 80 percent of the soil disturbance occurred in the 2- to 5-in. class in the dry normal surface condition. In the wet-wet slippery surface condition, approximately 50 percent of the soil disturbance occurred in the 5- to 12-in. class with less than 1 percent of the soil disturbance occurring in the 2- to 5-in. class.

1,000 Passes

37. For the 2-2-5 and 4-3-3 (HMMWV) vehicle force structures, over 80 percent of the soil disturbance occurred in the 1/2- to 2-in. class with approximately 1 percent will disturbance occurring in the 5- to 112-in. class in the dry normal surface condition. In the wet-wet slippery surface condition, approximately 46 percent of the soil disturbance occurred in the 1/2- to 2-in. class with approximately 12 percent soil disturbance occurring in the 2- to 5-in. class. For the 4-3-3 (8X8) vehicle force structure, approximately 76 percent of the soil disturbance occurred in the 1/2- to 2-in. class with about 1 percent of the soil disturbance occurring in the >12-in. class for the dry normal surface condition. In the wet-wet slippery surface condition approximately 49 percent of the soil disturbance occurred in the 2- to 5-in. class with less than 1 percent of the soil disturbance occurring in the 1/2- to 2-in. class. For the 5-5-0 vehicle force structure, approximately 30 percent of the soil disturbance occurred in the 2- to 5-in. class with about 59 percent soil disturbance occurring in the 5- to 12-in. class in the dry normal surface condition. In the wet-wet slippery surface condition, approximately 51 percent of the soil disturbance occurred in the 5- to 12-in. class.

PART V: SOIL EROSION IMPACTS

Objective

38. This section explains erosional effects and rates within maneuver areas subjected to variable factors of climate, terrain, and military vehicle activities. The following sections will outline the soil factors and processes influencing soil erosion at the YFC and the impact of soil erosion on the environment of YFC.

39. The response of loose, near-surface earth materials to vehicular traffic in arid regions such as the YFC is generally twofold:

- a. Accelerated deflation by wind follows disturbance of the vegetation cover, the armor layer of coarse particles, and/or the surface crust of chemically-bound particles, fungal filaments, algae or lichens, and comminution of rock fragments into silt and sand.
- b. Changes in microtopography caused by vehicular traffic are persistent. For example, Sheridan (1979) notes "some of the tracks made by General Patton's tanks and jeeps in the eastern Mojave during training maneuvers more than 35 years ago are still clearly visible."

Significance of Soil Erosion in Environmental Impact

Soil as a resource

40. Soil is America's greatest natural resource as a seed bed and nutrient source for vegetation, a foundation for structures, and a construction material. As a construction material, the term soil is used to include disaggregated rock materials without regard to specific pedogenic characteristics (silt, sand). In the YFC area the term "soil" is used to describe disintegrated rock materials. Soil data used in estimation of erosion impacts were taken from Soil Conservation service (SCS) maps and data for the YFC and surrounding areas (Rasmussen 1976, Lenfesty and Reedy 1985). The YFC soil resource provides training opportunities in arid/semi-arid terrain conditions and is analogous to other areas throughout the world. It is necessary to maintain ground surface training conditions, landform configurations, and vegetation areas, realizing that revegetation of denuded areas can take a long time in arid regions.

Significance of soil loss
loss to environmental systems

41. The maintenance of existing soil conditions in the YFC is important to both training and to minimization of any negative impacts on other environmental systems. Wind erosion of surface soils may expose plant roots to the abrasion of windblown sand, thereby killing the vegetation. Similarly, wind transported soil during concentrated field troop activities will negatively impact troop respiration and line-of-sight navigation, vehicle air intake mechanisms, and surface water resources. Although minimal at the YFC, removal of surface soils by water may expose plant roots, create gullies as barriers to effective troop maneuvers and cause increased sedimentation loads in river systems.

Factors Influencing Soil Erosion

Physical properties of soil

42. Soil fragments/constituents have varying characteristics of chemical composition, density, water content, and physical shape. These characteristics in conjunction with factors of parent rock material, climate, grain size percentages, age, organic content, vegetation cover, and topography give a unique character to each soil. Soils sharing similar characteristics are grouped into a soil type. In the YFC there are approximately 8 soil types indicative of unique combinations of soil forming factors. Each soil type has a unique set of physical properties including compactibility, trafficability, liquid limit, and permeability (see paragraphs 8 through 16). Soil compactibility refers to the amount of soil deformation resulting in a lesser soil volume. Soil compaction may result from traffic, shaking, or settling due to water saturation.

Drainage network

43. The development of drainage networks is the product of precipitation type and distribution, surface geology, rock structure (folds, faults, fractures), orientation of rock formations, recent topography, and tectonic history of an area. The drainage system of the YFC has developed in response to these factors over the last several million years. Training activities will not significantly alter the overall drainage system or system characteristics, however, localized accumulation of sediment or gullyng may take

place. If such local changes do occur, the impact will affect the flexibility of training options. As gullies increase in depth-to-width ratio, the first effect will be that the gully becomes a barrier to wheeled vehicles.

Secondly, the gully will increase in size until tracked vehicles cannot bridge the gap. Gullies may be a barrier to troop movement and will significantly lengthen the time necessary for troops to cross the area. Drainage areas and other natural physical parameters of military training areas are incorporated in a US Army Construction Engineering Research Laboratory (CERL) model for predicting physical degradation of training areas (Riggins and Schmitt 1984).

Vegetation

44. Vegetative cover of an area develops in response to various factors including the micro-climate, soil type, soil nutrients available, moisture, temperature, and slope. Vegetative cover increases soil permeability, holds soil in place, and protects the soil from disturbance. Vegetation helps lessen disturbance by decreasing the velocity of wind and water flowing over a soil and the interception of raindrops protecting bare soil from the relatively high energy of raindrop impact.

Purpose

Identify the impact of vehicles on soil

45. Natural phenomena of wind movement and water flowage, moving vehicle tires or tracks, and troop movements (foot traffic) all put a series of stresses on the soil. Vehicle traffic imparts normal and shear stress on the soil particles. The stresses are transferred from particle to particle within the soil. At some depth and distance laterally from the disturbance, the initial energy input is totally dissipated and there is no effect on the soil beyond that zone. The effects in the YFC of traffic will be the crushing of vegetation, grinding of soil particles against each other, relative movement between soil particles, disaggregation of soil particles, and transport of soil material. Dead vegetation will increase the availability of soil to erosion because of the dying root systems and the resulting increase in permeability due to root decay. The dead organic matter will also change the chemical composition of the soil pore water and thereby chemically effect the decomposition of soil fragments. Smaller clods and individual grains are more susceptible to aeolian and fluvial erosion. Some sediment will be caught,

perhaps temporarily, in vehicle tire treads and tracks. This sediment will be transported up into the near surface atmosphere and subsequently be released from the treads or tracks. This material so placed in the atmosphere will either settle near the release point, or be transported by wind to the nearest area where the wind velocity is insufficient to continue transporting the material. The material which settles will, by virtue of its kinetic energy, impact the soil surface, thereby releasing additional sediment into the atmosphere.

46. Soil disturbance and sediment yield. Technically, soil erosion is the uplifting of a soil particle from its position at rest. Once uplifted, the particle is transported a distance that may vary from less than a millimeter to perhaps tens of kilometers. Eventually the particle will be deposited when the transporting media energy necessary to transport the particle has diminished and the media has lost its carrying capability. The phenomena of erosion, transport and deposition are all important at the YFC. Erosion, transport and deposition of soil particles occurs at the YFC as it does everywhere else on earth. In the common use of the term "erosion," it is implied that the soil material is lost. However, soil lost from a given parcel may be redeposited in an adjacent parcel. At the YFC the determination of soil loss was done for each parcel of land knowing that traffic would impact some areas more severely than others. Parcel-by-parcel impact was determined because the information is needed to determine vegetation loss within each parcel. However, it must be realized that the soil removed from the most severely impacted parcel may be deposited on an adjacent parcel and never actually be lost from the YFC. It must be understood that soil eroded from a given parcel at the YFC, does not imply that all the eroded material is immediately entering a transporting media and being lost from YFC. For the purpose of this report, all activities of soil movement caused by vehicle traffic was termed "soil disturbance," the redistribution of the disturbed soil by natural processes such as wind and water was termed "erosion," and the eroded material actually predicted to leave YFC was termed "sediment yield." For example, soil erosion may be 20 tons/acre/year, but the sediment yield (that portion leaving YFC) from this parcel may only be 1 ton/acre/year. To put that in perspective, 20 tons/acre/year of soil erosion is approximately 0.125 in. of soil eroded from a one acre parcel per year. The sediment yield from the same parcel would be 1 ton/acre/year or a surficial loss of 0.0063 in./acre/year,

an undetectable loss. Sediment yield analyses were beyond the scope of this study.

Delineate and estimate area
and amounts of soil distur-
bance caused by vehicular traffic

47. The greatest effect on increased soil disturbance will be in any area defined as a training area. Any training area will have traffic activity in direct contact with native soil materials. These soils are susceptible to disturbance and the degree of disturbance will be a function of soil properties, moisture content, season, nature of track or tread, and the vehicle activity and load. The greatest erosion will be caused by wind during and after training activities. The YFC being in an arid environment has thin, poorly developed soils, sparse vegetation, and limited moisture. Under these climatic conditions, wind erosion of soils will be high and most probably will often result in localized conditions of low visibility. The quantities of wind transported soils will be significant and measurable. The silt and fine sand fractions contained in the soil and that produced by vehicular traffic may initially be transported down into the coarser, gravelly sections of the substrate by gravity and water. Water or fluvial erosion will be secondary due to the high rates of water infiltration and the lack of large quantities of surface water. "No erosion areas" have been delineated to indicate areas of rock and large size rock debris. Although erosion of rock masses is a continuous process, the amount of sediment contributed due only to the natural processes is insignificant. In many instances these rock areas are vertical or very steep slopes and are therefore not traversed by vehicles during training exercises. Similarly, areas delineated as "urban" or "off limits" will have no vehicular activity factor calculated for the soil erosion rates.

Environmental Factors Influencing Erosion

Regional geologic setting

48. Columbia Plateau Province. The Columbia Plateau Province covers southeastern Washington and adjoining portions of northern Oregon and western Idaho. The province consists of the Columbia River Basalt Group which is composed of five formations with a total of 14 geologic members. The lavas of the Columbia Plateau are flood-basalt covering an area of about 78,000 square

mile and have an estimated volume of 41,000 cubic mile. This Columbia Plateau Province is the earth's youngest recognized flood-basalt province and is age dated as having formed between 6 and 16.5 million years ago. The plateau is both a structural and topographic depression.

49. The YFC lies in the Yakima Fold Belt subprovince of the Columbia Plateau. The Yakima Fold Belt is characterized by linear anticlines and broad syncline trending eastward from the Cascade Range province to the west. The folding and associated faults were developed primarily during the later stages of basalt extrusion.

50. Pleistocene/Holocene history. Glacial deposits which include till, ice-contact-stratified drift, and outwash deposits are present in the northern and in the far western portions of the Columbia Plateau. In this area the plateau was overridden by the Okanogan Lobe of the Cordilleran Ice Sheet. Glacial deposits are characterized by eskers, ground moraine deposits, and large basalt erratics. Glacial drift occurs in the Kittitas, Wenatchee, and Chelan Valleys. Catastrophic flood deposits are widespread throughout the Columbia Plateau. These sediments resulted when ice dams in western Montana and northern Idaho were breached and massive volumes of water and sediment abruptly flooded across eastern and central Washington. The two main types of deposits resulting from the flooding were the flood gravels and slackwater sands.

51. The youngest of four loess units within the Columbia Plateau Province is informally called the post-Palouse loess (Rigby and Othberg 1979). This loess is a postflood deposit that is present in varying thicknesses throughout the YFC. It is in many areas capped by a weakly developed petrocalcic horizon. This loess is considered to be the result of deposition during the last 10,000 years.

Soils

52. Soils of the YFC. Soils in the YFC are of three general types as summarized below. This summary is derived from information in the terrain analysis study compiled at the US Army Engineer Topographic Laboratory Terrain Analysis Center (1978), Fort Belvoir, VA. It is necessary to specifically study the characteristics of the soil in the YFC because studies conducted by CERL at various Army installations indicated that impacts from tracked vehicle training activities varied between all sites studied (Goran, Radke, and Severinghaus 1983).

53. Soils range from limited areas of deep, well-drained alluvial loams (SM, ML) covering bottomlands to extensive areas of shallow, stony, soils overlying basalt. The development and properties of soils on the YFC have been, more or less, influenced by loess (ML, CLML), a silty wind-blown deposit. The loess is not of uniform thickness. In some cases it is many meters thick, but in other places erosion has stripped away the deposit leaving a very thin or discontinuous cover or exposed bedrock.

54. The most extensive soils occur on nearly level to very steep upland slopes of ridges and plateaus (Plate 1). These shallow, stony soils formed in loess mixed with weathered basalt (ML, GM). These shallow units are on steep broken stony land, smooth stony land, and scabland.

55. Another soil type forms in deep loess and is silty throughout. Some of these soils have a cemented lime-silica hardpan (caliche layer beneath, but near surface). Most of these have developed in thin loess mantling alluvium, old lacustrine deposits or basalt. The hardpan is almost impermeable and difficult to excavate with handtools. The upland soils are derived from tuffaceous sandstone, shale, or conglomerate. A very compact clayey subsoil is a notable feature of these soils.

56. The alluvial soils that occur in bottomland positions along major drainageways are deep, mostly well-drained and commonly stratified with coarse and fine-grained material in the substratum. These include riverwash (GP), recent deposits of loose cobblestones, gravel, sand, and some small areas of silt. Some of the loose sand from these deposits has been blown to adjacent upland areas.

57. Soil development rates. The time necessary for the formation of the various soils at the YFC is very long because of the lack of moisture and warm temperatures. The apparent lack of substantial precipitation, strong and prevalent winds, and moderate temperatures are not conducive to the rapid formation of substantial soil zones. The lack of precipitation produces sparse stands of low vegetation types. Remains of dead vegetation are readily oxidized and dried. These same remains are prone to wind transport or movement and are disintegrated by abrasion. Moderate temperature ranges, in conjunction with the sparse precipitation, retard chemical decomposition of mineral material necessary for soil development.

58. Influence of geologic history on soils. The parent material available for the formation of soils in the YFC is relatively young rock material.

In most instances the material is at most 10,000 years old and in many instances the soil material (loess) is possibly less than 100 years old. These conditions, in conjunction with the climatic conditions throughout the area for the last 10,000 years, indicate that the soils are immature soils. The soils lack the development of thick horizons which serve to increase the resistance of the soil to erosion.

59. Variability of soils on the landscape. The variability of the soil types in the study area is limited in a range and composition. Most of the area consists of silt/clay type soils on the slopes and in some cases the hilltop locations. On the hilltops and in the valley bottoms, gravel and sand deposits are the dominant soil types. The hilltops are wind swept and the valley bottoms are stream washed, which may account for the lack of fine grained fractions of clay and silt in these locations. Both the fine and coarse soil types are indicative of the glacial, fluvial, and aeolian history of the area.

60. Erodibility of soils The erodibility of the soils is a function of many variables, including vegetation, soil texture, and eroding fluid (wind and water) velocity and viscosity. Vegetation dissipates the energy of the fluid and thereby reduces its velocity and sediment transport capacity. Wind at higher velocities can transport up to medium sand size fractions of sediment, and usually transports the larger fractions within 3 ft of the ground surface. Water can transport larger fragments in suspension and can generally carry the same size fractions of sediment a greater distance than can wind. In the YFC, wind cannot transport fine fractions larger than medium sand. Fine sand fractions and often smaller size material are deposited in valleys downwind of hills. Deposition results from the loss of transport capacity of the winds as they mix with more stagnant valley air. Water can, on sufficient slope, transport large quantities of material by suspension, saltation, rolling, and bouncing. The soils most susceptible to erosion are the clays, silt, and sand fractions.

Climatic influences

61. Precipitation regime (including snow melt). Taking into consideration the transport capacity of water and climate regime, the maximum impact of water erosion will accompany spring runoff and long frequency storm (rain) events. Approximately 25 percent of the precipitation occurs as snowfall in the months of December and January. Average daily high temperatures do not

significantly exceed the melting point of snow until February, implying that February and March could be a period of significant water erosion. However, the snow precipitation may sublime and also undergo basal melting due to geothermal heat energy. The potential of spring runoff does exist. The other period of significant water erosion would occur with infrequent short duration storm events. During short storm events, soil infiltration rates may exceed precipitation rates and surface runoff may be initiated. These rain storm events occur in May and June. During these 2 months 20 percent of the annual precipitation is delivered to the surface of the YFC, often in the form of thunderstorms. The precipitation data for YFC is summarized as follows (average of a 12-year data base):

Mean Monthly Precipitation

	<u>in.</u>	<u>mm</u>
January	1.61	40.89
February	0.98	24.89
March	0.86	21.84
April	0.53	13.46
May	0.61	15.49
June	0.87	22.10
July	0.12	3.05
August	0.21	5.33
September	0.33	8.38
October	0.66	16.76
November	0.99	25.15
December	<u>1.05</u>	<u>26.89</u>
Total	8.80	223.52

62. Wind. The September through November period has the highest frequency of days with wind velocity greater than 17 knots. This period follows a period of dry conditions when almost all of the soil moisture in the upper surface is lost, resulting in a loss of soil cohesion. The effect of wind erosion is indicated in the visibility range data for YFC. The months of September through November have the greatest number of low visibility (less than 0.50 miles) days. The wind transport of silt and clay may account for the low visibility. Low visibility during December may reflect snowstorm visibility limitations as well as dust transport limitations.

63. Temperature. The mean daily minimum temperatures for the YFC range from 18° to 53° F, and the mean daily maximum temperatures range from 36° to

89° F. The YFC would undergo the same variations indicating moderately hot summer months (June through August) and moderately cold winters (November through January).

Soil Erosion Processes

Erosion during the dry cycle, wind

64. Maneuver-caused wind erosion impacts. If the velocity of the air in a open environment exceeds 2.25 mph, turbulent flow is initiated (Bagnold 1951). Since most winds exceed this velocity, the necessary turbulence for each material particle movement is achieved (Chepil and Woodruff 1963).

65. A soil composed of only submicron particles (clay) is nonerodible even when subjected to gale force winds. However, when these particles are mixed with particles 5 to 50 μ (silt) in diameter, the submicron particles become highly erodible (Hilst and Nickola 1959). Due to interparticle cohesion and low roughness associated with fine particles, winds that are capable of moving large diameter grains may not be capable of moving small diameter sediment such as silt and clay. Consequently, a homogeneous surface of silt or clay may be almost impervious to the effects of winds. Threshold velocities for undisturbed soils increase as overall clay content increases. When large aggregates of soil are considered, factors which act to decrease soil aggregate size (freeze-thaw) decreases the necessary threshold velocities, thereby making a surface more susceptible to erosion.

66. The major impact of maneuvers is the mixing of various grades of particle sizes, disaggradation of larger soil materials, and initiation erosion/transport by lifting particles into the wind (transport zone). This lifting is done by tank tracks, motor vehicle tires, and soldier foot traffic. Particles so lifted and transported then impact the soil surface down wind, thereby knocking (bumping) other particles into the transport zone. Successive such impacts (chain reactions) create dust and sandstorms.

67. In maneuver-caused impact studies conducted by Marston (1986) at Fort Bliss, grassland flats were distinguished from the dune sites on the basis of microtopography, vertical wind velocity profile, vegetation, and soil depth. The complete lack of aeolian transport in grassland flat sites was the most noteworthy contrast with the coppice dune sites.

68. Marston's study also included modeling of maneuver impact on sand transport. His study indicated that in a model, over 416,000 effective vehicle-days would be required in any one interval to cause a decrease in the threshold wind velocity by 2.24 mph. The model also indicated that threshold velocities exhibit rapid recovery following heavy maneuver activity to values reflecting the regeneration of a surface crust with the next precipitation event.

69. Marston's study indicates that:

- a. Values of threshold wind velocity are depressed, and a supply of loose sand is increased for aeolian transport by mechanical break-up of the surface crust, crushing particles to finer sizes as well as truncating and bisecting of aeolian land forms.
- b. The effects of maneuvers on the threshold are minor compared to the effects of antecedent precipitation; the destruction has less effect on the threshold than does the regeneration of the crust.
- c. The effects of maneuvers on dune microtopography are more persistent due to preservation of the impacts by the same surface crust.
- d. To minimize impacts, training maneuvers should be scheduled when winds are low and the threshold velocity is high (the crusts have formed).

70. Basic mechanics of aeolian processes. Problems associated with sand and dust movements by wind have been outlined by Cooke et al. (1982) and Goudie (1983) in terms of the responsible agent process: deflation-abrasion, transport, and deposition. Deflation causes loss of soil fertility, exposure of plant roots, removal of seeds, and scouring and abrasion of structures. Dust in transport reduced visibility which can in turn result in vehicle accidents, helicopter delays or accidents, reduced engine life, wear of helicopter and turbine blades, and harm to personnel health. The deposition of sand and dust in ditches, over roads and runways, and contamination of surface waters can all make field maneuvers difficult or impossible.

71. The threshold velocity is best considered as a dynamic variable in space and time, depending on the nature and persistence of a surface crust according to research conducted at Fort Bliss by Marston (1986). The effects of maneuvers on threshold wind velocity are short-lived with values adjusting quickly upward with precipitation events subsequent to the impact.

72. Tank maneuvers cause substantial decline in both vegetation density and cover. Such declines will affect soil stability, surface roughness, wind

velocity and dynamics near the surface, sediment entrainment, and sediment transport. Due to these factors, terrain types determine many of the attributes of soil erosion. In the YFC it is not only the soil types and wind velocity that determine erosion, but also the vegetation distribution and types.

73. In the YFC the conditions are different from Fort Bliss in two basic regards: the climatic conditions and the nature of the bedrock. The climatic conditions in YFC are desert conditions, but the temperature ranges are on the average lower than desert conditions. This enhances freeze-thaw activity that disintegrates rock fragments, but the cooler conditions retard the evaporative and precipitative activities conducive to the formation of a surface crust. The bedrock of the YFC is basaltic rock and therefore susceptible to chemical decomposition. This decomposition will free-up constituents necessary for the formation of the crust, namely the sodium and calcium for the formation of salts and carbonate intergranular cement. Binding strength of calcium carbonate increases as average particle size decreases. Therefore, the cement will have less effect on sandy soils than it will have on clayey or loamy soils. However, Chepil and Woodruff (1963) found that at 3 percent calcium carbonate content, defloculation of soil structural units is at a maximum. Above and below the 3 percent level, the defloculation effect is less.

74. The crust is not only destroyed by physical disruption by maneuver activities, but also by wind. At Fort Bliss, a wind storm with a maximum sustained 1 min. wind velocity of 41 mph and gusts of 60 mph destroyed virtually the entire crust in the study area with only remnant patches remaining. Crusts, which form as a result of rainfall (frequency and intensity), evaporation, and soluble salts availability began forming again within two weeks. Rainfall with too great an intensity will wash all soluble salts into lower soil horizons if soil permeability is high enough.

75. The April through October period of time at the YFC is a period of temperatures between 33° and 89° F, winds between 4 and 11 knots, and no precipitation on the majority of days. Higher wind gusts are recorded for many of these days, and the gusting will contribute to the initiation of dust and sand transport. At the YFC April is the month with the highest (7.7) percent frequency of wind speed equal to or in excess of 17 knots.

76. Factors influencing wind erosion. The critical factors influencing wind erosion are wind velocity, surface roughness, surface composition (size fractions), and surface disturbance. All of these factors are normally considered in regard to dry conditions. Altering the moisture content of the soil and temperature of the material will significantly alter the erodibility as can be imagined in a frozen ground condition.

Erosion during wet
cycle, running water

77. Erosion of earth materials by natural processes such as water and wind is a function of the energy of the eroding media and the stability of the surface materials being eroded. Water can transport large quantities of sediment, uplift larger masses of material, and initiate large scale mass wasting (landslides). Wind is less viscous and less dense than water. Therefore, wind will not be as significant an eroding agent as water in the YFC. The stability of the earth materials being eroded can be related to slope, degree of decomposition and disintegration, and magnitude of the eroding forces.

78. Basic mechanics. Wind and water will erode materials that cannot withstand the shear stress applied by the fluid. The "picking up" of material in the erosion process is a factor of buoyancy and rotational displacement. The fluid exerts a stress on an individual grain, and the grain begins to rotate from its position. the low pressure area created beneath the grain is alleviated by the fluids, air, or water flowing into the low pressure zone. The successive increments of rotation may be of short or long duration depending upon the magnitude of the shear stress and the viscosity of the fluid. Once dislodged, the grain of soil may be lodged in another location, be rolled along the surface, or be lifted into the fluid stream.

79. Factors. The factors affecting the removal and transport of soil material depend largely on the physical characteristics of the fluid and the physical environment of the soil grains. The characteristics of the fluid that is important are temperature, viscosity, sediment content or load, dissolved solids, turbulence, and velocity. The important factors of the soil grain environment include its mass, shape, size, permeability of surrounding material, surface roughness, and orientation.

Factors affecting rates of
water erosion of soil at YFC

80. The factors that affect soil erosion rates depend upon many soil parameters, many of which are related to natural factors and others related to the effects of land use. Various soil loss equations are used to determine loss rates, and these equations usually include such factors as rainfall and runoff, soil erodibility, slope length, slope steepness, management techniques, and conservation practices (Zingg 1940, Smith and Whitt 1947, Browning, Parish, and Glass 1947, Musgrave 1947, Van Doren and Bartelli 1956, Hudson 1961, Wischmeier and Smith 1978). Total runoff and runoff rate, and consequently, soil erosion increase directly with amount of rain and intensity. Infiltration rates of precipitation vary considerably, but fine grained materials in general have lower hydraulic conductivities. Coarse materials with initially high conductivities may undergo infiltration by fine grained material, thereby resulting in low conductivities. Fine grained material is difficult to detach but easy to transport. Coarse material is usually easier to detach but difficult to transport. Medium coarse materials are relatively easy to detach and transport. Interrill erodibilities of soils ranging in texture from clay to sandy loam varied from 5 to nearly 40 t/acre (Meyer and Harmon 1984) during a 3.9 in. rain at a rate of 2.8 in. per hr. The clay soils were least erodible. In soil erosion rates, studies for silt soils (3.9 in.) averaging 26.7 t/acre was lost. In the same study loam soils lost 18 t/acre, and clay loams lost 10 t/acre. These data result from studies in Iowa and can be generally related to other areas; however, the major factor other than soil type is soil development (structure and organic content). A more highly developed soil will have a lower erosion rate. For those reasons, erosion rates for Mississippi are about twice that of Iowa (Meyer and Harmon 1984). The lack of less well-developed soils in the YFC (arid region) indicated higher erosion rates for comparable soil types.

81. Sediment transport capacity of runoff increases rapidly as the flow channel gradient increases (Meyer et al. 1984). Sand-sized sediment transport by shallow, concentrated flow is low on a 0.2 percent slope, but increases 10 to 100 percent on a 1 percent slope. The erosion rate increases 5 to 50 times with a slope increase from 1.0 to 2.5 percent. The erosion rate in turn doubles at a 5 percent slope. This indicates that the low slope areas at YFC

will be susceptible to erosion rates much less than will the majority of the area that is greater than 5 percent (17.5 percent).

82. Preliminary model determinations for surface impact effects of tracked vehicles at YFC were conducted assuming conditions of the soils to be either wet or dry. In dry conditions, 50 passes of a tank would result in impacts to a depth of 2 to 5 in. In 1,000 passes, the impact would be greater than 5 in. but less than 12 in. Thousands of passes would be required to cause impacts deeper than 12 in. under dry conditions. Wet conditions have a significantly greater effect. Cleat area depressions favor the establishment of vegetation by trapping seeds and containing precipitation.

83. The effect of any physical activity on the surface earth material imparts energy to the material and can cause compaction, crushing, shearing, erosion, etc. Under a tank track the major effects would be compaction and disaggregation of soil constituents. This activity would be most pronounced directly beneath the cleats. In the track intercleat area and areas marginal to the track, the effect on the soil would be destruction of soil integrity and shearing, but of which increase erodibility of the earth materials by wind and water.

84. Iveson et al. (1981) studied the effects of off-road vehicles on soil compression, water infiltration rates, and soil erosion in the Mojave Desert of California. His results indicate vehicle tire effects increase soil compaction to a depth of several decimeters and that soil bulk density increased logarithmically with the number of vehicle passes. Similarly, the rainfall infiltration rates changed drastically. Prior to compaction, the runoff of water required 1.57 to 2.36 in. of rainfall. After compaction 0.43 in. of rainfall per hour was required to produce surface water ponding and runoff. Surface runoff from compacted areas was five times greater than from undisturbed areas. Sediment yields from the effect of compaction, etc., were 10 to 20 times greater. This sediment, once deposited, dried, and exposed to wind, is very susceptible to wind erosion.

85. Similar studies conducted by Prose (1985) examined the effects of an M-3 type tank on a bajada (slope 0 to 3 deg). The standing ground pressure of the tank was 14.8 psi. Penetrometer tests showed a large increase in resistance from 0 to 7.8 in. depth. The resistance increased up to 50 percent. A significant increase was noticeable to a depth of 11.8 in. The substrate was also affected out to a distance of 19.7 in. from the tank track.

Compaction was greatest in areas with the highest fraction of fine-soil materials. Prose's study indicated that elimination of the effects of soil compaction would take approximately 100 years. He also felt that the associated soil loss should be considered a permanent soil loss since regeneration of desert soils requires many centuries.

86. The results of traffic over soil materials causes track marks (ruts). These marks impede lateral surface runoff and in so doing channelize the flow of water. Rilling (erosion channels) can be initiated in tank disturbed areas with a slope of 1 to 2 deg. Channelized water flow has the increased capacity to erode sediment and initiate gully formation. The quantity of fine disassociated earth materials susceptible to erosion prior to vehicle passage is increased by processes described above. The channelization and increased quantities of fine fractions are primarily responsible for the increased sediment load carried by surface runoff. Any track disturbances that transect a surface parallel to the slope enhance erosion potential by providing flowing water a long reach. A long reach increases fluid flow velocity and therefore erosion transport potential.

87. Evidence of water erosion at YFC. Examination of aerial photographs* of the YFC reveals two scales of drainage networks on the landscape. A large, well-integrated dendritic network of streams is incised into the terrain. This well-developed channel network of perennial, intermittent, and ephemeral streams has probably been evolving in a similar manner for several tens of thousands of years. A smaller network of short straight channels (primarily gullies) may be seen in many areas. These small channels are generally less than 1,000 ft in length and flow directly into streams of all sizes. These gullies are most likely the product of historic soil erosion due to man's influence on removing or modifying the surface vegetation in some way. A belt of eroded soil may also be seen on the aerial photographs in the areas of gully erosion, illustrating the fact that most of the erosion at the YFC due to running water is directly related to the presence of a channel in the area.

* Aerial photographs supplied by US Army Engineer District, Seattle, WA.

Estimation of Possible Soil Erosion Rates

Erosion during the dry cycle

88. The primary factor of soil erosion during the dry cycle, approximately 80 percent of the year, is wind. Precipitation in the form of rainfall occurs so sporadically and in such insufficient amounts that the rainfall that does occur infiltrates the soil and does not generate runoff and appreciable erosion by running water. Therefore, the amount of soil loss that occurs during the dry cycle is a function of the amount of wind energy available to erode disturbed soil. Soil erosion amounts for the dry cycle are based on calculations including only wind effects.

89. Development of the wind erosion algorithm. In order to estimate the amount of wind erosion in the areas at YFC where wind erosion may occur, an algorithm was developed based on existing methods for estimating the amount of erosion due to wind. The wind erosion algorithm is based on the SCS method used to estimate wind erosion which considers various factors of the soil including wind erodibility group (WEG) and a climatic factor (C) (Chepil 1945, Woodruff and Siddoway 1965, Skidmore and Woodruff 1968). The wind erosion algorithm developed for this study was developed in consultation with SCS personnel in Kittitas County, Washington. The algorithm used for calculating total amount of erosion for the four vehicle scenarios during the dry period utilizes the standard SCS wind erosion equation plus a factor for soil disturbance by vehicular activity and a factor for the number of vehicular passes.

90. Data considered. Data used in developing the wind erosion algorithm include the wind erodibility group (WEG) and allowable soil loss values (T) for each soil type taken from SCS data. Within a given area, usually a county, a multitude of soil types are mapped due to their unique characteristics. These soils can be grouped on the basis of their grain size, moisture content, etc., as well as wind erodibility. Each group WEG has similar tons/acre/year loss due to wind erosion. These groups are developed primarily on grain size characteristics due to diversity, complexity, and variability of moisture contents. For this study, WEG factors were established by examining grain size data and relating the factors to experience in erosion studies conducted at the WES. Soil moisture data were included in establishing the WEG because the worst case scenario was used (i.e., the condition of total dry surface conditions). A factor for depth of soil disturbance by vehicles and a

factor for the number of vehicle passes were also derived. Using this algorithm, calculations were made for each 164- by 164-ft (50- by 50-m) pixel area at YFC for estimating maximum possible erosion due to wind during the dry period. The wind erosion algorithm is stated as:

$$e \text{ (wind)} = C \times I \times D \times M/T$$

where

E (wind) = maximum possible soil erosion rate during the dry cycle, in tons/acre/year

C = climatic factor for wind erosion (0.50)

I = wind erosion factor for wind erosion group, where

WEG (Rock), I = 0.0

WEG (GP), I = 1.0

WEG (GC, GM), I = 3.0

WEG (SM), I = 35.0

WEG (CLML, ML), I = 50.0

WEG (CL), I = 86.0

D = vehicle disturbance factor where

Depth of disturbance = 0 - 0.5 in., D = 1.1

Depth of disturbance >0.5 in., D = 1.2

M = number of vehicle passes factor, where

Low density traffic, M = 1.0

Medium density traffic, M = 3.0

T = SCS soil loss factor (tons/acre/year)

91. Data not considered. Parameters are not considered in calculation of wind erosion during the dry period include the occurrence of rare summer or spring precipitation events where precipitation intensity may exceed infiltration rate of the soil, significance of wheels versus tracks in throwing soil into the air, spatial differences in wind intensity and direction, and spatial differences in soil moisture. All fine grain size materials are dry enough at some time during each season to be susceptible to wind erosion. Fine to medium grain size sand and silt contents, without significant quantities of clay, facilitate a loss of sediment cohesion due to drying. From available soil moisture data, it was determined that, with the exception of creek

bottoms, probably all the surficial soils are dry enough to offer no moisture related resistance to wind erosion during the dry period.

92. Discussion of dry normal condition maps. Examination of the disturbance maps for the dry season for all four vehicular combinations indicated that vehicular traffic will have a substantial impact on soil erosion during the dry period (Plates 33 through 35, 39 through 41, and 45 through 47). In comparing the different vehicular force structures, it is apparent that the maps are similar and that once the upper 1 in. of soil is disturbed by a wheel or track, susceptibility of the soil to erosion by wind is high. One inch of soil disturbance is sufficient to give rates of wind erosion in excess of 40 tons/acre/year for many of the soils. A primary factor, however, in generating soil erosion due to wind is the number of vehicular passes. In the main maneuver areas, maximum soil erosion due to wind will occur as each vehicle that passes over the highly erodible soil will generate dust into the air. Soils that are stoney and have minimal susceptibility to soil erosion due to wind may increase in erodibility due to the crushing of the sediment by the grinding action of the tracked vehicles. Consequently, soils that were not susceptible to erosion may become highly susceptible to erosion by wind after a hundred passes of a tracked vehicle.

Erosion during the wet cycle

93. Erosion during the wet cycle (less than 20 percent of the year) was estimated through the consideration of erosion due to running water only. An assumption was made that during the wet cycle, soil moisture was significantly high to eliminate the probability of soil erosion due to wind action. Consequently, the total amount of soil erosion for the wet cycle was estimated using a water erosion algorithm, stated as:

$$E \text{ (water)} = T + T \times K \times H \times D \times S$$

where

$E \text{ (water)}$ = maximum possible soil erosion rate during the wet cycle,
in tons/acre/year

T = SCS soil loss factor (tons/acre/year)

K = SCS soil erodibility factor (varies from 0.15 to 0.49,
depending on soil type)

H = channel occurrence factor, where:

If a spring occurs in parcel, $H = 1.0$

If upper canyon channel in parcel, $H = 1.1$

If lower canyon channel in parcel, $H = 1.2$

If permanent channel in parcel, $H = 1.3$

D = depth of disturbance factor where:

If 0 - 0.5 in., $D = 1.0$

If >0.5 - 2.0 in., $D = 1.1$

If >2.0 - 5.0 in., $D = 1.2$

If >5.0 - 12.0 in., $D = 1.4$

If >12.0 in., $D = 1.0$

If NOGO, $D = 1.0$

S = slope factor, where:

If 0 - 2 percent, $S = 1.0$

If >2 - 5 percent, $S = 1.1$

If >5 - 10 percent, $S = 1.2$

If >10 - 20 percent, $S = 1.3$

If >20 - 40 percent, $S = 1.4$

If >40 percent, $S = 1.6$

94. Development of the water erosion algorithm. The development of an algorithm for erosion during the wet cycle was based on the consideration of a number of factors, including the erodibility of the soil (K) and the allowable erosion factor (T) obtained from SCS data, a slope degree factor derived from topographic maps, the occurrence of various types of channel on the landscape, and the depth of soil disturbance by vehicle force structure.

95. Data not considered. Data not considered in the development of the wet cycle soil erosion algorithm include the influence of a track versus a wheel on erosion by running water, the orographic effect of the landscape, the slope length, the influence of vegetation, the change of soil factors by vehicular traffic, and the nonhomogeneous distribution of traffic. Tracks have different effects on surficial soils than wheels with respect to erosion by running water. Tracks may increase infiltration rate through soil disturbance and increasing surface roughness, thereby decreasing runoff and soil erosion. However, wheels concentrate flow and decrease infiltration of the soil through soil compaction, thereby increasing runoff and soil erosion. Wheels may also concentrate flow along slopes instead of downslope, thereby decreasing runoff and soil erosion. Both tracks and wheels widen stream channels at crossings and increase local stream bank erosion, adding soil contribution to the stream. Thus, it may be seen that wheels and tracks have

complex impacts on the soil in terms of erosion by running water. No attempt was made to try to quantify these differing impacts on the soil in terms of erosion by water.

96. Data considered. The distribution of precipitation, a primary factor in runoff generation, may be affected by elevation. This orographic effect may occur when elevations go through a range of 3,281 ft, which occurs at YFC. Discussions with SCS personnel in Kittitas County indicate that precipitation distribution is affected by elevations with higher elevations receiving greater precipitation.* However, upon examination of the aerial photographs of the YFC, there appears to be very little relationship between the distribution of natural vegetation and elevation. Natural vegetation would be directly related to soil moisture and consequently precipitation. There appears to be no relationship between areas of greater elevation and areas of increased soil moisture as evidenced by changes in vegetation distribution and type. Consequently, no orographic factor was developed for runoff development. Also, in terms of vegetation, it is assumed that where vehicular traffic occurs, all vegetation will be destroyed. Consequently, vegetation as a buffer will not be preserved in areas of high vehicular traffic. Also, the change of the physical properties of the soil due to vehicular traffic in terms of erosion of the soil by running water is not considered. Many of the soils at YFC have a low erodibility factor. This factor will probably be increased as these soils are exposed either to tracked or wheeled vehicle traffic.

97. A major factor in the generation of soil erosion due to running water is the length of the slope. Unfortunately, data were not generally available for inclusion of the slope-length factor in the wet cycle soil erosion algorithm. An additional effect of slope on soil erosion is the concentration of vehicular traffic in corridors on higher slopes. In many areas, especially those of lower slopes, as the slope increases, both tracked and wheeled vehicles will select specific areas as traffic corridors. These trails will become concentrated areas of erosion.

98. Discussion of wet-wet slippery condition maps. Examination of the soil erosion maps for the wet cycle for all vehicle force structures indicated that erosion during the wet cycle is considerably less than during the dry

* Ron Peyton. 1988. Personal Communication.

cycle (Plates 36 through 38, 42 through 44, and 48 through 50). The principal reason for this is that very little rain actually falls during the wet cycle and what does fall generally occurs in intensities less than the infiltration rate of the soil. Consequently, runoff and related soil erosion is minimized. An exception to this is the rapid melting of winter snowfall. Discussions with SCS personnel in Kittitas County reveal that most of the snow melt occurs within a 48 hr period from mid to late February. This rapid production of water to local channels may cause flash flooding and related soil and stream bank erosion.

99. Use of the wet erosion maps. Comparison of the soil erosion maps for the wet cycle with those for the dry cycle show the relative influence of the soil erodibility factor and slope factor for the wet cycle versus the traffic and number of pass factors for the dry cycle. During the wet cycle, the depth of the disturbance may actually be a positive factor in increasing the infiltration capacity of the soil. The increased infiltration would therefore decrease runoff and inhibit the potential disturbance effect that would occur without infiltration. Consequently, vehicular traffic has a much less deleterious impact upon the soil environment during the wet cycle than during the dry cycle when erosion primarily occurs due to wind action.

Relative soil erosion severity

100. The impact of soil erosion during both the dry and wet cycles (12 months) as a function of allowable soil loss is shown in Plates 51 through 59. The "Soil Erosion Severity" maps show the maximum erosion for each 164- by 164-ft (50- by 50-m) parcel at YFC with respect to erosion loss and soil regeneration. The assumption is that every parcel gets all of the vehicle traffic considered in the analysis. These maps, like Plates 33 through 50, are useful for predicting areas of relative amounts of soil erosion. The soil erosion severity maps display areas having specific ratios of soil loss to soil generation. In areas with a soil severity index of less than one, the soil regeneration rate is sufficient to maintain a soil resource. Soil material is lost, but the soil forming processes recover a soil system status over a sufficient period of time. Since most of the soil eroded in the 164- by 164-ft (50- by 50-m) parcel will be deposited in another parcel at YFC, the maps do not represent soil loss or sediment yield. Plates 51 through 59 indicate the amount of soil that may be mobilized by erosion. Deposition of mobilized or remobilization of the same soil is not

accounted for in the analyses. Probably 90 percent of all of the sediment mobilized by vehicular traffic in the YFC will remain within the YFC due to deposition of the sediment in adjacent parcels. This estimate is based on previous field experiments, research, and observation conducted by WES.

Recommendations

Minimizing soil erosion by area selection

101. The environmental impact of soil disturbance at YFC by vehicular traffic may be minimized in several ways. An obvious way to reduce the potential for soil disturbance is to restrict traffic to centers of activity connected by arteries (tank trails and roads). Since only a few passes by wheeled or tracked vehicles are necessary to completely destroy the surface vegetation and disturb the soil to a depth of 1 in., total elimination of traffic in all but selected areas (activity areas and connecting corridors) would substantially reduce the amount of soil disturbance. The soil that was eroded from the corridors and activity areas would be redeposited nearby, with the possible exception of stream crossings, where eroded soil might be ultimately transported out of the YFC into the Columbia River. Examination of aerial photographs of YFC reveals that this practice of trail and road establishment connecting obvious locations for activity areas actually occurs, and many large tracts in maneuver areas on YFC exhibit minimum environmental impact due to maneuver activities. Establishment of activity areas and corridors between them is in keeping with standard battlefield operations.

102. Some areas are more susceptible to soils erosion damage by vehicle traffic than others. Areas of silty (loess covered) soils are highly susceptible to wind erosion and should be avoided. Long steep slopes dissected by many small channels and gullies are obviously prone to erosion by running water and are likely areas for significant soil erosion impact. Areas of wind shadow and gentle topography minimize the potential for soil erosion throughout the year and offer the best locations for vehicle traffic to reduce soil erosion.

Minimizing soil erosion
by time-of-year activities

103. Soil erosion may also be reduced substantially by considering the best time of year for training on different areas at YFC. Training during the months with greatest precipitation and snow melt should be minimized in the areas most subject to erosion by running water. During periods of maximum wind velocity, upland slopes covered by silty soils should be avoided.

104. An integrated training program which considers all three of the above recommendations could substantially reduce the amount of soil erosion which may be produced by training activities and significantly affect the related adverse environmental impacts.

PART VI: EFFECTS OF TRAFFIC IN SELECTED NATURAL RESOURCES

Background

105. This section introduces the information base used to evaluate the effects of military vehicle traffic on selected natural resources at the YFC. It includes a recapitulation of vehicle soil disturbance and erosion data and introduces basic environmental data.

Disturbance by vehicle traffic

106. As described in paragraph cc, five categories of soil disturbance were identified for the YFC: minimal, slight, moderate, high, and severe. Tables 1, 2, and 3 show the number of acres in each soil disturbance category, by force structure, for both dry-normal and wet-wet slippery conditions. These data were obtained by multiplying the total YFC acreage, obtained during the mapping process, by the percentages from Figures 2 through 7. Note that as the force structures move away from the 3-3-5, the level of soil disturbance increases for both the dry-normal and wet-wet slippery conditions. Under all conditions, the 5-5-0 force structure is predicted to cause the highest degree of soil disturbance.

107. NOGO areas for all force structures and conditions are primarily associated with the sharp rocky crests of ridges, the steep embankments in certain creeks and the Columbia River and Alkali Canyon, and soil-associated problems such as traction and strength. For purposes of this analysis, it is assumed that areas predicted to be NOGO on the soil disturbance maps are physically off-limits to traffic and that areas not included in the soil disturbance NOGO areas are accessible and therefore vulnerable. However, it should be noted that although these areas are NOGO according to the mobility model, there may be some attempts to traverse the areas, thereby resulting in some damage.

Soil erosion

108. The pattern of erosion for dry conditions (wind) is such that the highest rates of erosion are predicted along the south border of the YFC, a wide band along Selah Creek, a band south of and along Alkali Canyon, the eastern portion of Hanson Creek, and the vicinity of Squaw Creek (e.g.,

Table 1

Acres Affected by Soil Disturbance Level, Low Scenario (10 Passes)

<u>Force Structure, Soil Disturbance Category</u>	<u>Dry-Normal Acres/Percent</u>	<u>Wet-Wet Slippery Acres/Percent</u>
3-3-5 (HMMWV)		
Minimal	229,187 (87.1)	153,932 (58.5)
Slight	0	0
Moderate	0	0
High	2,894 (1.1)	0
Severe	0	0
NOGO	6,315 (2.4)	84,465 (32.1)
4-3-3 (8X8)		
Minimal	198,664 (75.5)	526 (0.2)
Slight	0	128,145 (48.7)
Moderate	0	0
High	0	0
Severe	2,894 (1.1)	0
NOGO	36,838 (14.0)	109,726 (41.7)
5-5-0 (M60A3)		
Minimal	0	0
Slight	232,082 (88.2)	13,420 (5.1)
Moderate	0	119,461 (45.4)
High	0	0
Severe	0	0
NOGO	6,315 (2.4)	105,516 (40.1)

Note: Urban/off-limits = 24,734 acres (9.4 percent), water = 0 acres (0 percent).

Table 2
Acres Affected by Soil Disturbance Level, Medium Scenario (50 Passes)

<u>Force Structure, Soil Disturbance Category</u>	<u>Dry-Normal Acres/Percent</u>	<u>Wet-Wet Slippery Acres/Percent</u>
3-3-5 (HMMWV)		
Minimal	229,187 (87.1)	153,932 (58.5)
Slight	0	0
Moderate	0	0
High	2,894 (1.1)	0
Severe	0	0
NOGO	6,315 (2.4)	84,465 (32.1)
4-3-3 (8X8)		
Minimal	0	0
Slight	198,664 (75.5)	127,092 (48.3)
Moderate	0	1,579 (0.6)
High	0	0
Severe	2,894 (1.1)	0
NOGO	36,838 (14.0)	109,726 (41.7)
5-5-0 (M60A3)		
Minimal	0	0
Slight	0	0
Moderate	232,082 (88.2)	526 (0.2)
High	0	132,335 (50.3)
Severe	0	0
NOGO	6,315 (2.4)	105,516 (40.1)

Note: Urban/off-limits = 24,734 acres (9.4 percent), water = 0 acres (0 percent).

Table 3
Acres Affected by Soil Disturbance Level, High Scenario (1,000 Passes)

<u>Force Structure, Soil Disturbance Category</u>	<u>Dry-Normal Acres/Percent</u>	<u>Wet-Wet Slippery Acres/Percent</u>
3-3-5 (HMMWV)		
Minimal	0	0
Slight	229,187 (87.1)	121,567 (46.2)
Moderate	0	32,365 (12.3)
High	2,894 (1.1)	0
Severe	0	0
NOGO	6,315 (2.4)	84,465 (32.1)
4-3-3 (8X8)		
Minimal	0	0
Slight	198,664 (75.5)	526 (0.2)
Moderate	0	128,145 (48.7)
High	0	0
Severe	2,894 (1.1)	0
NOGO	36,838 (14.0)	109,726 (41.7)
5-5-0 (M60A3)		
Minimal	0	0
Slight	0	0
Moderate	77,887 (29.6)	0
High	154,195 (58.6)	132,881 (50.5)
Severe	0	0
NOGO	6,315 (2.4)	105,516 (40.1)

Note: Urban/off-limits = 24,734 acres (9.4 percent), water = 0 acres (0 percent).

Plate 33). There is also a mapped pocket of high erodibility at the junction of Training Areas 1B and 1C (e.g., Plate 40). (However, its higher class may be an artifact of the classification process; the actual rate of erosion in that area is 50.9 tons/acre versus 30.0 tons/acre for the next lower rate). When the rate of erosion changes, e.g., with more passes, the pattern tends to remain the same. The Off-limits areas are not included in these calculations.

109. The lowest rates of predicted soil erosion and lowest numbers of acres affected are from wind erosion and occur with the 4-3-3 (8X8) force structure, 10 passes (Plate 39). The highest effects are also from wind erosion and occur with the 1-0-6 and 5-5-0 force structures, 1,000 passes (Plates 35 and 47). Compared to the 4-3-3 (8X8), the 3-3-5 and 5-5-0 force structures have a higher percentage of area subject to erosion. Under dry conditions, erosion rates increase with the number of passes of all force

structures. Maps depicting water erosion show a similar pattern to those for wind, but the magnitude of erosion is less.

Natural features

110. The general topography of YFC, plateaus interfaced with intermittent steam beds and associated soil banks and rocky cliffs, and the low precipitation, produce an ecosystem occupied by species that are highly adaptable to harsh climatic conditions. The most striking features of the YFC are Selah Creek Canyon, Alkali Canyon, and the bluffs and slopes leading to the Columbia River. These provide different habitats than the plateaus and broad hills covering most of the installation.

111. The streams of the YFC have primarily intermittent water flows. The riparian classification map (Plate 60) was based on data collected by Shapiro and Associates, Inc. (1989). It shows the dendritic pattern and land cover classifications for the 853.3 linear miles of branches. A description of the mapping approach and cover classification was reproduced in Tab 1 on page 103. Table 4 provides a detailed classification of riparian vegetation and the extent of each type.

Table 4
Classification and Extent of Riparian Cover Types

<u>Classification</u>	<u>All Riparian Areas</u>		<u>Riparian Areas >200 ft wide</u>	
	<u>Linear Miles</u>	<u>Percent of Miles</u>	<u>Acres</u>	<u>Percent of Acres</u>
Palustrine emergent marsh (PEM)	31.5	3.7	4.7	10.4
Palustrine forested (PFO)	12.9	1.5	12.4	27.6
Palustrine scrub shrub (PSS)	113.8	13.3	11.4	25.3
Palustrine forested/emergent marsh (PFO/PEM)	0.3	TR	13.8	30.7
Palustrine open water and open water/forested (POW, POW/PFO)	0.3	TR	2.7	6.0
Riparian stream bed, unvege- tated and unclassified (RSB)	584.3	68.5	0	0
Riparian stream bed, exposed rock (RSB _n)	38.6	4.5	0	0
Riparian stream bed, upland vegetation (RSB _v)	<u>71.6</u>	<u>8.4</u>	<u>0</u>	<u>0</u>
Total	853.3	99.9	45.0	100

112. Bodies of water are distinctive features in this arid landscape. Table 5 and Plate 61 depict all known springs, seeps, and ponds on the YFC. Seeps were verified by Shapiro and Associates (1989) and springs are from the YFC Special Map (1:50000) or from Mr. Eric N. Anderson (Personal Communication (December 1989)). Some of the springs, seeps, or ponds may be encompassed within the NOGO condition on the most conservative disturbance map (Plate 15: 3-3-5, dry condition, 10 passes) and would not be affected by training. However, because of inherent map inaccuracies, they were included as potentially accessible to vehicles. Four of the springs from the YFC Special Map are inside off-limits areas and eight from Anderson are outside the YFC.

Vegetation associations

113. Six general vegetation associations were identified by Pacific Northwest Laboratory (PNL) (1988) in work completed for I Corps and Fort Lewis (Plate 62). PNL's map was based on 1986 Landsat scenes and has an overall accuracy of 78 percent. The extent of each category of land cover association is in Table 6 and each type is discussed below.

114. Shrubland/wheatgrass/Sandberg bluegrass. This cover type is the most prevalent vegetation community on the YFC under existing land use conditions, which include military training and grazing by cattle and sheep. Shrubland can exist in several scenarios, depending upon elevation, level of disturbance, and other physical factors such as available water and quality of soil. In general, this cover type is big sagebrush (Artemisia tridentata) with predominant understory vegetation of bluebunch wheatgrass (Agropyron spicatum) and Sandberg bluegrass (Poa sandbergii). A mixture of "minor" shrubs can also be found in this cover type, including green rabbitbush (Chrysothamnus vicidiflorus), gray rabbitbush (C. nauseosus), and antelope bitterbush (Purshia tridentata). Other grasses will be mixed with the wheatgrasses and bluegrass, including needlegrass (Stipa spp.), cheatgrass (Bromus tectorum), six-weeks fescue (Festuca octoflora), and western fescue (F. occidentalis). In addition, there could be a variety of forbs growing under and between the shrubs.

115. Water. The only open, permanent, or semi-permanent water on the YFC is located at Taylor and Eaton Ponds. During snow melt or after precipitation events, and especially during early spring months, the major creeks on

Table 5
Location of Seeps, Springs, and Ponds

<u>Training Area Number</u>	<u>UTM Coordinate</u>	<u>Wetland Type</u>	<u>Remarks</u>
3A	025857	spring	Squaw Creek Canyon
3B	100932	spring	
3B	128923	spring	
3B	133917	spring	
3B	142919	spring	McDonald Springs
3B	142920	spring	McDonald Springs
3B	110900	pond	Eaton Pond
4	160915	spring	
4	158907	spring	
4	160897	spring	
4	163906	spring	
4	164901	spring	
4	170891	spring	
4	182876	spring	
5	235862	spring	Hanson Creek
5	310882	seep	
6A	252843	seep	
6A	209840	spring	
6A	248815	spring	
6A	243790	seep	Alkali Canyon
6A	260794	seep	Alkali Canyon
6A	262789	seep	Alkali Canyon
6A	267783	seep	Alkali Canyon
6A	268783	seep	Alkali Canyon
6A	269782	seep	Alkali Canyon
6A	272787	seep	Alkali Canyon
6A	215775	seep	Alkali Canyon
6A	219777	seep	Alkali Canyon
6B	302794	spring	Borden Springs
6B	307798	spring	Borden Springs
6B	308795	spring	Borden Springs
7A	270761	seep	
7A	280770	seep	
8A	179735	spring	
8A	191738	seep	
8A	158753	seep	
8A	160758	seep	
8A	180785	spring	
8B	160680	pond	Taylor Pond
9B	040742	spring	
10C	096633	spring	Coyote Spring
10C	043629	spring	
11C	158644	spring	
11C	203638	spring	

(Continued)

(Page 1 of 4)

Table 5 (Continued)

<u>Training Area Number</u>	<u>UTM Coordinate</u>	<u>Wetland Type</u>	<u>Remarks</u>
11B	218642	spring	
11B	219656	spring	
1A	016816	spring	Anderson data
	020830	spring	Anderson data
	031812	spring	Anderson data
	050800	spring	Anderson data
1C	037716	spring	Anderson data
2A	026826	spring	Anderson data
	045804	spring	Anderson data
2B	063799	spring	Anderson data
3A	050895	spring	Anderson data
3B	094931	spring	Anderson data
	118929	spring	Anderson data
	145924	spring	Anderson data
	148919	spring	Anderson data
	150917	spring	Anderson data
	152935	spring	Anderson data
4	163932	spring	Anderson data
	171926	spring	Anderson data
	162922	spring	Anderson data
	191907	spring	Anderson data
	181890	spring	Anderson data
	164877	spring	Anderson data
5	218902	spring	Anderson data
	210880	spring	Anderson data
	227858	spring	Anderson data
	267919	spring	Anderson data
	270887	spring	Anderson data
	290886	spring	Anderson data
	299898	spring	Anderson data
	304901	spring	Anderson data
	318882	spring	Anderson data
	289850	spring	Anderson data
6A	218832	spring	Anderson data
	218816	spring	Anderson data
	215803	spring	Anderson data
	273818	spring	Anderson data
	269806	spring	Anderson data
6B	231850	spring	Anderson data
	252838	spring	Anderson data
7A	261753	spring	Anderson data
8A	148760	spring	Anderson data
	154760	spring	Anderson data
	173752	spring	Anderson data
	178743	spring	Anderson data
	186740	spring	Anderson data

(Continued)

(Sheet 2 of 4)

Table 5 (Concluded)

<u>Training Area Number</u>	<u>UTM Coordinate</u>	<u>Wetland Type</u>	<u>Remarks</u>
8B	188714	spring	Anderson data
9A	128745	spring	Anderson data
10C	042681	spring	Anderson data
	044661	spring	Anderson data
	070659	spring	Anderson data
	090656	spring	Anderson data
	097649	spring	Anderson data
	050630	spring	Anderson data
	068638	spring	Anderson data
	093640	spring	Anderson data
	108643	spring	Anderson data
	085628	spring	Anderson data
	107632	spring	Anderson data
	102623	spring	Anderson data
11A	150656	spring	Anderson data
	153658	spring	Anderson data
	158657	spring	Anderson data
	162655	spring	Anderson data
	163653	spring	Anderson data
	171652	spring	Anderson data
11B	198670	spring	Anderson data
	227655	spring	Anderson data
	228653	spring	Anderson data
	219648	spring	Anderson data
11C	152643	spring	Anderson data
	202633	spring	Anderson data
	210629	spring	Anderson data
	217636	spring	Anderson data
	221624	spring	Anderson data
	232593	spring	Anderson data
Dud	252652	spring	Anderson data
Area 12	270653	spring	Anderson data
	284652	spring	Anderson data
	281632	spring	Anderson data
	290633	spring	Anderson data
	299621	spring	Anderson data
	295614	spring	Anderson data
	313627	spring	Anderson data
	321624	spring	Anderson data
	327637	spring	Anderson data
	338629	spring	Anderson data
13A	238730	spring	Anderson data
	232714	spring	Anderson data
	245717	spring	Anderson data
	270720	spring	Anderson data

(Continued)

(Sheet 3 of 4)

Table 5 (Concluded)

<u>Training Area Number</u>	<u>UTM Coordinate</u>	<u>Wetland Type</u>	<u>Remarks</u>
13A	260699	spring	Anderson data
	289715	spring	Anderson data
13B	303722	spring	Anderson data
	305716	spring	Anderson data
	291710	spring	Anderson data
	282688	spring	Anderson data
	292683	spring	Anderson data
	285676	spring	Anderson data
	298675	spring	Anderson data
	302693	spring	Anderson data
	309675	spring	Anderson data
	324691	spring	Anderson data
	328688	spring	Anderson data
	332687	spring	Anderson data
	327675	spring	Anderson data
	343663	spring	Anderson data
	354664	spring	Anderson data
13C	229668	spring	Anderson data
	272667	spring	Anderson data
12	270635	spring	Nelson Springs
12	272636	spring	Nelson Springs
12	272612	spring	Black Rock Springs
12	300641	spring	
12	303619	spring	
12	337618	spring	
13B	331670	spring	
13B	324723	spring	
13B	340712	spring	
13B	343702	spring	
13B	323664	spring	
13B	309667	spring	
15	040742	spring	Selah Springs

(Sheet 4 of 4)

Table 6
Classification and Extent of Cover Types on the YFC

<u>Cover Type</u>	<u>Total Land Area</u>		<u>Area of Potential Traffic¹</u>	
	<u>Acres</u>	<u>Percent of Area</u>	<u>Acres</u>	<u>Percent of Area</u>
Shrubland/wheatgrass/ ₂ Sandberg bluegrass	124,258	48.0	115,862	49.4
Open water	12	tr ³	12	tr
Exposed rock	5,525	2.1	5,525	2.4
Wheatgrass/Sandberg bluegrass/cheatgrass	82,138	31.7	70,486	30.1
Cheatgrass	8,279	3.2	8,279	3.5
Sand dunes/surface mines	96	tr	96	tr
Bluebunch wheatgrass	12,262	4.7	10,555	4.5
Agricultural/riparian ⁴	106	tr	106	tr
Sandberg bluegrass/ stiff sage	<u>26,362</u>	<u>10.2</u>	<u>23,472</u>	<u>10.0</u>
Total	259,038 ⁵	9.9 ⁶	234,393	99.9

1. Area of Potential Traffic = Total Land Area - Acres of each cover type in Off-Limits areas shown in Plates 15 through 32.
2. Scientific names area given in the following section.
3. tr -- trace, i.e., percent too low to register at one decimal point.
4. A more detailed map of the riparian areas is in Plate 60.
5. Total does not equal total YFC acreage because the Landsat image did not cover approximately 3000 acres on the western boundary of YFC.
6. Percentages do not total 100 due to rounding.

the YFC have water flows. Some flows exist nearly year-round where springs feed creeks.

116. Exposed rock. Over 5,000 acres of rocky ledges and cliffs occur on the YFC. These are primarily associated with Selah Creek and other creek canyons, high ridges, Alkali Canyon, and the bluffs adjacent to the Columbia River. Rock areas large enough to be mapped at the scale used by PNL are primarily in the northeast quarter of the YFC. Additional cliffs and talus slopes are also present, e.g., Selah Canyon.

117. Wheatgrass/Sandberg bluegrass/cheatgrass. This mixed plant community is the second largest land cover component at the YFC. Plant species located here include native grasses and forbs, but may also include introduced Asian wheatgrasses and specially-developed dryland legumes planted to stabilize soil and to provide more forage for livestock. Most recent plantings consist of Siberian wheatgrass (Agropyron sibiricum) and ladak alfalfa (Medicago spp.). This cover type, and portions of the shrubland/wheatgrass/bluegrass cover type, are also the most intensively managed portions of the YFC with regard to livestock grazing use (Andersen 1984). The wheatgrass/bluegrass/cheatgrass community as depicted by the PNL occurs at mid-elevation on YFC slopes, interspersed with the big sagebrush and stiff sagebrush communities.

118. Cheatgrass. Pure stands of cheatgrass are the result of high disturbance such as fire. Cheatgrass is an introduced, relatively unpalatable plant species that aggressively colonizes bare or disturbed soils. On YFC, over 8,000 acres have been converted to this cover type, primarily in the northeastern part of the range and near Borden Springs.

119. Sand dunes/surface mines. The small acreage of this cover type occurs on the western portion of the installation.

120. Bluebunch wheatgrass. Bluebunch wheatgrass is a native grassland community that is interspersed to some extent by forbs and other grasses. This general cover type is a minor component of the overall YFC. A cover of bluebunch wheatgrass in good condition is considered high quality grazing land for livestock in the western US, and it receives considerable grazing pressure on the YFC.

121. Agricultural/riparian. Almost no row cropping occurs within the YFC. Some of the more recent (at the time of their mapping) plantings of

wheatgrasses and legumes contribute to this acreage. Discussion of riparian areas will use the map in Plate 60.

122. Sandberg bluegrass/stiff sagebrush. Bluegrass and stiff sagebrush (Artemisia rigida) generally occur together on the high slopes and ridges of the YFC and on the thinnest soils. This cover type, as indicated on the PNL map, also includes small higher areas with sparse stiff sagebrush that provide a unique vegetation, and includes many forbs that occur nowhere else on the YFC. These thin soil areas are highly susceptible to damage from any training during wet months. Tracks made in the wet season will be evident for decades and will contribute to the general overall erosion problem on the YFC. Much of this cover type occurs within the Impact Area.

123. Other vegetation. Although not indicated on Plate 62, incidental or non-native vegetation occurs on the YFC around abandoned ranch and homestead sites. These plant species are not a problem and are not spreading, and generally consist of such species as silver poplar (Populus alba), Lombardy (P. nigra), native wild roses (Rosa spp.), Kentucky bluegrass (Poa pratensis), and other remnant cultivated plant stands. In areas where disturbance has occurred, weedy species such as knapweeds (Centaurea spp.), Russian thistle (Salsoli kali), and cheatgrass have invaded and pose a threat to the integrity of the YFC (Personal Communications, Mr. Eric N. Andersen, Range Conservationist, YFC, and Mr. Jon Haput, Range Conservationist, Bureau of Land Management, Reno, NV, May 1989).

Plants and animals

124. Plant and wildlife species of special interest and known or thought to be present on the YFC are given in Table 7, with their status or reason for interest and associated cover type. The Washington Natural Heritage Data System (WNHDS) (1989) was the source for the listings. Site preferences for plants are primarily from Hitchcock and Cronquist (1973); information for Columbia milk-vetch is from Personal Communication with Mr. John Gamon, Botanist, Washington Natural Heritage Program, November 1989. Animal preferences are from several western field guides.

125. Observations of plant and wildlife locations were provided by WNHDS as Township, Range, and Section data. These were translated into approximate locations on the YFC Special Map (1:50000) and are shown as training area locations in Table 8. Actual locations could be up to a mile and a half different and perhaps even in a different training area when the location

Table 7
Biota of Special Interest, Reason for Interest,
and Preferred Habitat

<u>Common and Scientific Name</u>	<u>Reason for Interest</u>	<u>Preferred Habitat</u>
<u>PLANTS</u>		
Columbia milk-vetch, <u>Astragalus columbianus</u>	Federal Candidate, State Threatened	Dry sandy loam soils in big sagebrush/Sandberg bluegrass
Porcupine sedge, <u>Carex hystricina</u>	State Sensitive	Wet ground near streams
Shining flatsedge, <u>Cyperus rivularis</u>	State Sensitive	Wet areas, lowlands
Beaked spike-rush, <u>Eleocharis rostellata</u>	State Sensitive	Alkaline or calcareous areas, salt marshes
Giant helleborine, <u>Epipactis gigantea</u>	State Sensitive	Streambanks, near seeps and springs
Balasat daisy, <u>Erigeron basalticus</u>	Federal Candidate, State Threatened	Cliff crevices in basaltic canyons
Umtanum desert-parsley, <u>Lomatium quintuplex</u>	State Sensitive	Rocky basaltic slopes
Hoover's deser-parsley, <u>Lomatium tuberosum</u>	Federal Candidate, State Threatened	Rocky hillsides, talus
Henderson's ricegrass, <u>Oryzopsis hendersonii</u>	State Sensitive	Dry, rocky soils in sagebrush
<u>ANIMALS</u>		
Prairie falcon, <u>Falco mexicanus</u>	Under consideration for state listing	Open areas, canyons and cliffs
Golden eagle, <u>Aquila chrysaetos</u>	Under consideration for state listing	Sagebrush/grasslands, canyons and cliffs
Ferruginous hawk, <u>Buteo regalis</u>	Federal Candidate State threatened	Sagebrush/grasslands, canyons and cliffs
Swainson's hawk, <u>Buteo swainsoni</u>	Under consideration for Federal and state listing	Open areas

(Continued)

Table 7 (Concluded)

<u>Common and Scientific Name</u>	<u>Reason for Interest</u>	<u>Preferred Habitat</u>
<u>ANIMALS (Continued)</u>		
Sage grouse, <u>Centrocercus urophasianus</u>	Federal Candidate	Sagebrush/grasslands
Burrowing owl, <u>Athene cunicularia</u>	Under consideration for state listing	Open areas, Sagebrush/ grasslands
Merriams shrew <u>Sorex merriami</u>	Under consideration for state listing	Sagebrush/grasslands
American painted lady <u>Cynthia virginienensis</u>	Under consideration for state listing	Streambeds, open areas (not within YFC border)

Table 8
Location of Selected Plant and Wildlife Observations

<u>Training Area</u>	<u>Species</u>	<u>Approximate Location in Training Area</u>
<u>PLANTS</u>		
1A	Basalt daisy	SW corner (canyon
5	Columbia milk-vetch Hoover's desert parsley	Eastern quarter NW corner (ridge)
6B	Giant helleborine Beaked spike-rush Columbia milk-vetch Porcupine sedge Shining flatsedge	Borden Springs Borden Springs SE corner Borden Springs Borden Springs
7A	Columbia milk-vetch	Eastern edge
7B	Columbia milk-vetch	Western edge
10C	Henderson's ricegrass	Western edge
13B	Umtanum desert-parsley Hoover's desert-parsley Columbia milk-vetch	West central East central edge East central edge
<u>ANIMALS</u>		
1A	Burrowing owl	SW corner (canyon)
1B	Prairie falcon	North central edge (canyon)
	Ferruginous hawk	NW corner (canyon)
	Golden eagle	NW corner (canyon)
1B	Swainson's hawk Sage grouse Sagebrush vole	SW corner SE corner South central corner
1C	Merriam's shrew	Near range central
2A	Ferruginous hawk Swainson's hawk Sage grouse	NW corner NW corner NE Corner
2B	Swainson's hawk	East central edge
3A	Prairie falcon Golden eagle Burrowing owl Sage grouse	SW corner SW corner West central edge NE corner
3B	Burrowing owl	NW corner (above bivouac site)
4	Swainson's hawk Sagebrush vole	NW and south central NW corner

(Continued)

Table 8 (Concluded)

<u>Training area</u>	<u>Species</u>	<u>Approximate Location in Training Area</u>
<u>ANIMALS</u>		
5	Prairie falcon	SE corner (cliffs)
6B	Prairie falcon	SE corner (cliffs)
7B	Prairie falcon	North central edge (cliffs)
8A	Swainson's hawk	NW and south central
8B	Swainson's hawk	SE corner
9A	Ferruginous hawk Sagebrush vole	North central edge North and south central edges
9B	Sage grouse Swainson's hawk Merriam's shrew	West central edge NW corner West central edge
11A	Swainson's hawk Prairie falcon	South central edge SE corner
11B	Swainson's hawk	North central edge and SE corner (dud area)
	Burrowing owl	NE corner
12	Swainson's hawk Sagebrush vole	NE and NW corners South central
13B	Prairie falcon	East central edge (cliffs)
13C	Ferruginous hawk	SE corner

is listed on the edge of a training area. Also, raptors generally hunt over a wide area, and the observations for those species are primarily of nesting areas. Locations in the table should be viewed as being indicative of a preferred type of area rather than an absolute location. In addition, observation dates are unknown. Training areas are shown in Plate 63. The known distribution of Columbia milk-vetch in 1984, as mapped by WNHDS, is shown in Plate 61. These observations are in addition to the general locations provided in Table 8.

126. Table 9 and Plate 61 shows the locations of all known leks on the YFC in 1989. All locations except the two traditional leks from the YFC Special Map were determined by Battelle Northwest Laboratory in March and April 1989 and may be new leks. Many of the observations from the WNHDS are in proximity to the Battelle sightings and well within mobility bounds of the sage grouse.

Table 9
Sage Grouse Lek Locations

<u>Training Area</u>	<u>UTM Coordinates</u>	<u>Maximum Number of Birds Observed</u>
1A	004760	7
	018754*	2
1B	031738	8
2A	058844	55
2B	068834**	N/A
3A	031881	5
	043873*	4
	054913	3
3B	070874	7
8B	164695	12
9A	123698	16
9B	054710	22
	040722**	N/A

* Approximate locations.

** Approximate locations of traditional leks plotted on YFC Special Map and Plate 61.

Impact Assessment

Introduction

127. The primary impacts addressed in this study relate to the alteration or destruction of soil structure and vegetation and subsequent effects on fish and wildlife caused by the different force structures. The disturbances from traffic, as reported in earlier parts of this report, represent the worst case scenario, in that all but the obvious exclusions (e.g., impact and dud areas) are assumed to be affected. Because of practical considerations such as constricted movement caused by topography, the actual impact may occur on a smaller percentage of the area. However, cumulative impacts on soils and vegetation from repeated use could bring the total impact on a localized area to 100 percent. Because of these ambiguities, specific acreage and locations are not reported; indices and percentages are used to show relative impacts among the various force structures.

Basis for impact assessment

128. Soil, plants, and animals are closely associated with each other. Climate and the chemical and physical properties of the soils in large part determine the form and species composition of plants that will be supported on the site, and biotic processes of the plants alter the soil over time. This alteration occurs at the YFC at a slower rate than in areas which produce more plant biomass, e.g., Fort Lewis. Activities of animals also affect soil properties, e.g., burrowing by invertebrates and mammals aerates the soil, and enhances mixing of elements, and increases fertility and organic matter (Brady 1974, Chew 1978).

129. Direct effects of traffic on the soil include compaction (Merriam and Smith 1974; McEwen and Tocher 1976; Dawson, Countryman, and Fittin 1978; Goran, Radke, and Severinghaus 1983) and physical rearrangement or loss of soil layers; e.g., reduction or removal of organic matter (McEwen and Tocher 1976; Goran, Radke, and Severinghaus 1983). Indirect or resulting impacts include decreased pore space and water availability, decreased water infiltration, and increased run-off and erosion (McEwen and Tocher 1976; Goran, Radke, and Severinghaus 1983; Payne, Foster, and Leininger 1983). These effects depend on the characteristics, timing, and intensity of traffic, with impacts generally increasing to a threshold. After that threshold is reached, no additional direct damage occurs. For example, once compacted, the soil does

not respond to additional traffic with additional compaction (Cole 1979; Goran, Radke, and Severinghaus 1983; Merriam and Smith 1974; McEwen and Tocher 1976). However, indirect impacts such as erosion can continue to increase.

130. The model used to predict soil disturbance from vehicles does not consider compaction, so this impact cannot be quantified. Compaction from any source (wildlife or hiking trails, vehicles) negatively affects plants by reducing soil aeration and moisture-holding capacity so plant growth is reduced or eliminated. Effects on animals that live below the surface include death or displacement, depending on the severity of compaction. High soil moisture decreases soil resistance to compaction because water acts as a lubricant, thereby increasing the ability of soil particles to move and lodge against each other (McEwen and Tocher 1976).

131. Direct effects on vegetation include crushed or exposed roots (Merriam and Smith 1974, McEwen and Tocher 1976), crushed or broken vegetation, immediate death, inability of roots to penetrate compacted soil (Goran, Radke, and Severinghaus 1983; Environmental Laboratory 1986), and disrupted building of root reserves (Sheehan and Clampitt 1984, Wilson 1988). With heavy soil disturbance and deep rutting that destroys the rooting zone, little or no vegetation can grow. Indirect effects of traffic on vegetation are reduced plant vigor and photosynthetic efficiency from physical damage (Severinghaus, Riggins, and Goran 1979; Goran, Radke, and Severinghaus 1983), reduced resistance to drought and cold from a shallow root system, and death because of loss of vigor and tolerance to adverse conditions.

132. In addition to direct and indirect effects on specific plants, changes in species composition and dominance occur. Soil disturbance alters the competitive advantage of native species by generally favoring exotic (Cole 1979; Goran, Radke, and Severinghaus 1983; Sheehan and Clampitt 1984; Wilson 1988).

133. Minor disturbance results from one-time traffic, with impacts primarily to surface vegetation (Landing and Doerr 1983; Goran, Radke, and Severinghaus 1983). Further disturbance results in break down of organic matter and removal of the top layers of soil. With increased soil disturbance, sensitive plant species are destroyed, and vegetation composition shifts to those species that are tolerant of soil disturbance, such as knapweed.

134. Major components of the environment and wildlife habitat include water, topography, specific plant species, the physical structure of vegetation, and substrate. Of these components on the YFC, vegetation and soils are the most directly affected by vehicles, and will be used as the basis for evaluating the differential impacts of the three force structures. Impacts will be addressed separately for the rangeland and the riparian zones.

Prediction of soil and vegetation loss

135. One way to estimate impacts is to examine changes in habitat complexity. Several regional studies in a large number of vegetation associations have shown the importance of complexity to the quality of these ecosystems (e.g., Brown 1985); one way to describe complexity is with the number of layers present. Layers can be identified, mapped, measured, monitored, and managed. Short (1984) found a strong relationship between the number of vertical layers present and the potential number of wildlife species that could be supported on site. Other studies have shown that a higher number of layers allows more habitat complexity, and that basically "more is better". More complexity refers to the maximum number of layers for each type; e.g., the maximum number of layers in an emergent wetland is less than in riparian forest. However, that does not reduce the importance of the wetland as a cover type and wildlife habitat.

136. Three layers have been identified on the YFC that contribute to habitat quality by increasing complexity when they are present and functioning. Woody vegetation in the form of shrubs occurs over much of the range, although trees are found in some riparian zones and the cantonment area. Woody vegetation on the YFC is generally taller than the herbaceous plants, resulting in two layers based on height and plant volume. The third layer, substrate or soil, could be divided into surface and subsurface because of differential wildlife use. However, the fragility of the soils at YFC and the effects of vehicles are such that once the surface is affected, so is the subsurface; therefore only one soil layer is used in this analysis. The subsurface that includes burrows in rocks is a valid layer but assumed to receive no structural impact from traffic. Burrows in other areas would be seriously impacted due to compaction or physical destruction.

137. To predict the relative impact of each force structure, Table 10 was constructed based on the percentage of vegetation and soil productivity that might be lost in each category of disturbance. These percentages were

based on personal observations, studies conducted at other installations, and literature on recreation impacts, but are still subjective.

Table 10
Predicted Percent Loss of Vegetation and Soil Productivity
by Soil Disturbance Category

<u>Disturbance Category</u>	<u>Dry-Normal</u>		<u>Wet-Wet Slippery</u>		<u>Dry and Wet Soil Productivity</u>
	<u>Woody</u>	<u>Herbaceous</u>	<u>Woody</u>	<u>Herbaceous</u>	
Minimal	5	10	10	25	15
Slight	15	25	30	50	40
Moderate	30	50	75	100	60
High	75	100	100	100	80
Severe	100	100	100	100	90

138. The percent loss of vegetation refers to destruction. That is, 15 percent loss of woody vegetation predicted from the slight level of disturbance means that if 100 shrubs were subjected to such a degree of traffic, 15 of them would be uprooted, crushed to death, or injured to the degree that growth is severely reduced.

139. The rationale for the predicted losses in vegetation includes the following. Bury, Lukenbach, and Busack 1978 reported in Sheridan 1979 that "moderate" and "heavy" off-road vehicle use reduced shrub biomass by an estimated 50 to 70 percent, respectively. In areas of concentrated activity, 95 percent loss occurred. Goran, Radke, and Severinghaus 1983 reported that vegetation was disturbed to a greater degree during the wet cycle at Fort Riley, Kansas.

140. The soil disturbance categories, as rut depth, are one expression of soil damage and loss. However, the relationship between rutting depth and soil productivity is curvilinear, with the top portion of the soil horizon being proportionately higher in fertility and more critical to plant production and survival than the lower portion of the profile. For example, physically removing 25 percent of the soil profile results in far more than 25 percent loss of soil productivity.

141. Soil productivity, as used here, is a combination of soil chemical and physical properties, as well as the quality of the resulting plant

community. The degree of impact of various soil disturbance levels on soil productivity was estimated by considering the effects of soil disturbance (rutting depth) on lost or reduced organic matter, reduced fertility and depth, soil compaction, and shifts in plant productivity from desirable to undesirable species. An incremental loss in soil from the top of the profile has a greater impact on soil productivity than the same increment of soil loss in the lower part of the soil horizon. It is also evident that soil loss, due to the climatic regime, is irreplaceable in the foreseeable future.

142. Based on Range Site Descriptions, it was determined that there was an inverse relationship between percent slope and soil depth, as would be expected. For this study, the intermediate soil slope/soil depth data (10-20 percent slope and 30 in. depth) were used to evaluate soil productivity loss due to soil disturbance category. The loss in soil productivity was expressed as a percentage of total current soil productivity. The same levels of soil disturbance would have a much greater impact on soil productivity on steeper slopes with more shallow soils, and less impact on more level and deeper soils.

Comparison among force structures-Rangeland

143. The index of soil disturbance between wet-wet and dry conditions for each force structure and layer is shown in Table 11. The 3-3-5 force structure was used as the baseline for comparing relative impacts of the proposed force structures. The following calculations were used to establish the index:

- a. (Acres in each disturbance category from Tables 1-3) \times (each predicted loss from Table 10), totaled for each force structure = A_{va} (vegetation acres lost).
- b. A_{va} divided by total disturbed acres in force structure = percent of total vegetation and soil lost for force structure = P_n , where n = force structure.
- c. P_{3-3-5} divided by P_{3-3-5} = index for force structure 3-3-5
 P_{4-3-3} divided by P_{3-3-5} = index for force structure 4-3-3
 P_{5-5-0} divided by P_{3-3-5} = index for force structure 5-5-0.

144. Table 11 should be viewed in a relative sense and all comparisons should be made only within columns by condition (sets of three). Comparisons between columns (scenarios) are invalid due to the use of different

Table 11
Relative Impacts of Force Structure on Vegetation
and Soil Productivity

<u>Low Scenario (10 Passes)</u>						
<u>Force Structure</u>	<u>Dry-Normal</u>			<u>Wet-Wet Slippery</u>		
	<u>Woody</u>	<u>Herbaceous</u>	<u>Soil</u>	<u>Woody</u>	<u>Herbaceous</u>	<u>Soil</u>
3-3-5 (HMMWV)	1.0	1.0	1.0	1.0	1.0	1.0
4-3-3 (8x8)	1.1	1.1	1.0	3.0	2.0	2.7
5-5-0 (M60A3)	2.5	2.3	2.5	7.0	3.8	3.9
<u>Medium Scenario (50 Passes)</u>						
<u>Force Structure</u>	<u>Dry-Normal</u>			<u>Wet-Wet Slippery</u>		
	<u>Woody</u>	<u>Herbaceous</u>	<u>Soil</u>	<u>Woody</u>	<u>Herbaceous</u>	<u>Soil</u>
3-3-5 (HMMWV)	1.0	1.0	1.0	1.0	1.0	1.0
4-3-3 (8x8)	2.7	2.4	2.6	1.0	1.0	1.0
5-5-0 (M60A3)	5.1	4.6	3.8	3.3	2.0	2.0
<u>High Scenario (1,000 Passes)</u>						
<u>Force Structure</u>	<u>Dry-Normal</u>			<u>Wet-Wet Slippery</u>		
	<u>Woody</u>	<u>Herbaceous</u>	<u>Soil</u>	<u>Woody</u>	<u>Herbaceous</u>	<u>Soil</u>
3-3-5 (HMMWV)	1.0	1.0	1.0	1.0	1.0	1.0
4-3-3 (8x8)	1.0	1.0	1.0	1.9	1.6	1.4
5-5-0 (M60A3)	3.8	3.2	1.8	2.6	1.6	1.8

baselines. In all cases, both wet and dry, the general trend in impacts is to increase as the force structure is changed from 3-3-5, with the 5-5-0 having the greatest impact.

145. Under dry conditions, the greatest impact differences are associated with the medium scenario, with the 4-3-3 (8x8) force structure affecting the vegetation and soils about 2.5 times as much as the 3-3-5 force structure. The 5-5-0 force structure appears to affect the vegetation and soils four to five times as much. However, in both the low and high scenarios, the 3-3-5 and 4-3-3 (8x8) force structures appear to have the same magnitude of impact, while the 5-5-0 force structure is only two to three times as great.

146. Under wet-wet conditions, the analysis is similar. In a low-use scenario, the relative impacts increase for all three force structures, with the 4-3-3 (8X8) being two to three times greater than the 3-3-5, and the 5-5-0 approximately four to seven times greater than the 3-3-5. Under the medium scenario, the 3-3-5 and 4-3-3 (8X8) are the same, while the 5-5-0 impacts only two to three times as much. Under the high scenario, the difference in change between the 3-3-5 and 4-3-3 (8X8), and between the 4-3-3 (8X8) and 5-5-0 is approximately the same. Once again, as in the dry conditions, there appears to be a threshold of impact, although it is apparently reached between 10 and 50 passes.

Comparison among force
structure - Riparian Areas

147. Resolution of the mobility or erosion models is inadequate to examine short reaches of narrow, yet critical, riparian areas. However, by describing current conditions in the riparian zone and knowing the relative effects of the force structures, we can predict relative changes that will result from the proposed change in force structure can be estimated.

148. The vegetation of the YFC, similar to most of the Western US, probably suffered from overgrazing in the late 1800's and early 1900's. Overgrazing resulted in changes in plant species composition, reduced range condition, and increased erosion and sedimentation. Due to the slow nature of area systems to respond to change, evidence of the detrimental impacts of past grazing remain. However, conditions have improved significantly since the land was purchased by the Army.

149. Riparian systems, in particular, have been affected by past overgrazing due to the presence of water. Livestock spend proportionately more time in riparian areas and consume forage in greater amounts than in adjacent upland areas. In addition to livestock grazing, mechanical activity, fire, and invading plant species such as cheatgrass have disturbed riparian areas.

150. The current state of the riparian zone was described by Shapiro and Associates (1989) in two ways, as explained in Tab 1. The first was type and degree of soil disturbance (livestock, mechanical, fire, or cheatgrass, low to high) and the second was erosion as evidenced by degree of incision.

151. Disturbance in Hanson Creek is largely from livestock and mechanical activity. Fire and livestock (secondarily) are responsible for the high

soil disturbance classification of Corral Canyon. Small portions of Squaw Creek (mechanical and fire), Alkali Canyon (primarily fire and secondarily livestock), and Cold Canyon (combination of mechanical, livestock, and fire) were also rated high. Most of the eastern part of Selah Canyon and the western half of the North Fork of Squaw Creek have high disturbance from mechanical causes.

152. Degree of erosion was catalogued for 90.4 miles of the riparian system (Plate 64). The linear miles and percent of total are in Table 12. The most severe problems, those "which may require structural stabilization of both stream bed and banks" (refer to Tab 1) for restoration are in Selah, Hanson, Alkali, and Cold Creeks.

Table 12
Type and Extent of Riparian Erosion

<u>Erosion Category</u> <u>Depth</u>	<u>Miles of</u> <u>Erosion</u>	<u>Percent</u> <u>of Total</u>
E1 (0 to 2 ft)	35.7	39.5
E2 (2 to 6 ft)	22.0	24.3
E2U (2 to 6 ft, unpaired terraces)	1.2	1.3
E3 (6 to 12 ft)	17.0	18.8
E3U (6 to 12 ft, unpaired terraces)	2.4	2.7
E4 (> 12 ft)	<u>12.1</u>	<u>13.4</u>
Total	90.4	100.0

153. In a riparian zone, continuity of vegetation is a significant factor in habitat quality, sediment control, water quality, and other factors (Ohmart and Anderson 1986). In an unperturbed system, some discontinuity is expected because of differential water and substrate characteristics and natural disturbances such as fire. In a perturbed system, additional discontinuities will occur because of the impacts. Drainage on the YFC were examined by reach, with reach defined by land cover component (Table 13).

Table 13
Discontinuity of the Riparian Area

<u>Drainage</u>	<u>Total Miles</u>	<u>Total Number of Breaks*</u>	<u>Number of Breaks/ Total Miles</u>	<u>Number of Vegetated Miles</u>	<u>Number of Breaks/ Vegetated Miles</u>	<u>Percent of Miles with Vegetation</u>
North Fork Squaw	10.5	0	0	0	0	0
Squaw	12.2	13	1.07	9.0	1.44	74.0
Selah	23.8	13	0.55	9.7	1.34	40.7
Hanson	12.5	15	1.20	6.8	2.19	54.7
Cottonwood	6.5	13	2.00	2.5	5.12	39.1
Alkali	12.2	10	0.82	10.1	0.99	83.0
Corral	8.8	17	1.93	5.8	2.91	66.4
Sourdough	6.1	10	1.64	3.0	3.34	49.0
Cold	8.9	18	2.02	7.4	2.45	82.6

* Breaks = discontinuity, where riparian vegetation changes to either exposed rock, unclassified riparian stream bed, or upland vegetation.

** Vegetated miles = only those miles of the main stream channel containing Palustrine Emergent Marsh (PEM), Palustrine Forested (PFO), or Palustrine Scrub Shrub (PSS) vegetation.

154. The North Fork of Squaw Creek has no breaks because it has no vegetation. Excluding that drainage, Cotton wood is the most discontinuous based on vegetated miles and has the lowest amount of vegetation; Alkali is the most continuous and has the most vegetation. Because of its length, Selah exhibits a variety of conditions, including a low discontinuity over its short stretch of vegetative cover.

155. No single form of riparian zone characterization is sufficient to fully describe the current environment and predict future conditions. For example, Cold Creek has evidence of disturbance and severe erosion, but is vegetated over 83 percent of its length. Hanson Creek, however, has low vegetative cover, a high degree of preventable soil disturbance, and severe erosion. The current force structure of 3-3-5 and proposed 5-5-0 can access most

of the riparian areas in dry conditions. Therefore, without controls, the direct damage due to vehicles and indirect damage from fire, invasion of exotic, and increased erosion will increase over the current condition. The 4-3-3 (8X8) is not able to access a large portion of the riparian areas under the same dry conditions. Access under wet conditions is less with all force structures, but damage is of greater magnitude.

Effects on plants,
animals, and communities/habitats

156. The biota listed in Table 8 will be affected or unaffected based on where they occur relative to access by vehicles or individuals and by the amount of habitat damage the vehicles cause. Each listed species is briefly discussed below. Because of the relatively large resolution of the maps and the small scale of some environmental changes at YFC, very few species are listed as being included in a soil disturbance NOGO area. The result is a potentially conservative statement of predicted impacts. Species preferences are limited as much as possible to the environment of the UFC. Major plant communities are discussed after the special animal species.

157. Columbia milk-vetch. Columbia milk-vetch occurs on the YFC exclusively on the eastern side. A Special Use area has been designated that is part of Training Areas 6B, 7B, and 13B. However, according to observation data provided, this area covers less than half of the colony sites of the species. The other colonies of Columbia milk-vetch occur in Training Areas 5 and 6B are mostly outside NOGO zones. The extent of this species may be expanding due to wildfires from training causing reduced vegetative competition (Shapiro and Associates 1987), although excessive or uncontrolled fires are not expected to benefit the species.

158. Basalt daisy. The basalt daisy has only one known colony on the YFC, located in Training Area 1A. This species prefers steep, rocky slopes, and may occur on other parts of the YFC. However, the known colony located on the south slopes of Selah Creek Canyon should not be impacted because of the steep slopes which prohibit vehicle access.

159. Hoover's desert-parsley. Two colonies of Hoover's desert-parsley have been located on the UFC, one in the northeast corner in Training Area 5 and one in the southeast corner in Training Area 13B. Both occur on talus slopes, and both apparently occur in NOGO areas because of steep slopes, so they should not be impacted by any changes in training levels or equipment.

Shapiro and Associates (1987) recommend special protection during March and April when the plant reproduces.

160. State-sensitive plants. Beaked spike-rush, porcupine sedge, giant helleborine, and shining flatsedge are all State-sensitive species that occur in the wetter areas within the YFC. One colony of each species has been identified on the YFC, all of which could be impacted by training unless they are designated off-limits. However, all wetland areas (springs, seeps, and ponds, and most riparian areas) should be environmental NOGO zones due their uniqueness. If that designation is made, these state sensitive plants will be protected.

161. Two of the state sensitive plant species occur in drier areas. The Umtanum desert-parsley also has only one colony identified on the YFC. It is located on steep, rocky, dry slopes in Training Area 13B, and is probably in a mobility NOGO area due to the roughness and steepness of the terrain. Therefore, there should be no impacts on this desert-parsley. Henderson's ricegrass prefers rocky areas in sagebrush and occurs in Training Area 1C. It is not protected by a soil disturbance NOGO designation and is therefore susceptible to damage by maneuvers.

162. Prairie falcon. There are seven nesting sites known for prairie falcons on the YFC (Table 8). These very swift raptors are aerial hunters who prey primarily on other birds, especially ground birds. They also eat rodents, lizards, and large insects. Home ranges for prairie falcon pairs presented in Peterson (1988) ranged from 40 to 71 square miles. Prairie falcons nest on cliffs and in rocky outcrops (Peterson 1988) and escarpments (Evans 1982). One pair of falcons requires 0.25 miles of undisturbed cliffs for nesting (Maser, Thomas, and Anderson 1984). Vehicles and individuals coming within 55 yards of the nest during nesting season are likely to decrease reproductive success (Harmata, Durr, and Geduldig 1978). Peterson (1988) gave an example of habituation to disturbance by prairie falcons, but it was to aircraft.

163. Golden eagle. The golden eagle has two recorded breeding observations on the YFC. Most individuals of this species require cliff sites for nesting; in their absence, trees are used (Call 1979). Research in the Idaho Birds of Prey area showed the golden eagle hunted over an area up to four miles from the nest, primarily along the canyon and associated draws (US Department of Interior 1979). In several parts of the United States, home

range sizes for a pair of golden eagles ranged from 19 to 73.5 miles² (Peterson 1988). Lagomorphs (Lepus spp. and Sylvylagus spp.) are the preferred and primary food item (Bolen 1975, Collopy 1983).

164. Impacts to this species from training will occur if the birds are disturbed while nesting, and if their prey base is reduced because of habitat destruction. Peterson (1988) reported that eagles would leave their nest when people came within 0.3 mile. The probability of successful reproduction decreases with an increase in the number of times the bird leave the nest, which results in increased exposure for the eggs or young. Because of their relatively specialized diet, golden eagle populations will decrease when their prey base decreases (Peterson 1988).

165. Ferruginous hawk. The ferruginous hawk inhabits dry open country, often hunting from perches of rocks, tall shrubs, etc., a distance of half to a little over a mile from its nest site (Jasikoff 1982). Wakeley (1978) found the density of vegetative cover more important in determining hunting location than prey density; sites with < 5 percent cover were preferred even though hunting success was low. However, as Jasikoff (1982) pointed out, there is a threshold of cover below which insufficient prey will be present. The majority of this hawk's diet is jackrabbits, with other species of small mammals taken as available or when jackrabbit numbers are low.

166. Preferred nest sites are trees, but the ferruginous hawk also nests on cliffs, outcrops, human-provided structures, and the ground (Call 1979, Jasikoff 1982). Peterson (1988) found nests no more than three miles from water, and that factor significant in nesting success. There are four current observations of breeding on the YFC (Table 8). The species is considered to be stable or declining slowly (Evans 1982), with data inadequate to decide which is the correct status. A source in Jasikoff (1982) cited sensitivity to human disturbance (especially when eggs are present) and habitat alteration as the factors most responsible for any decline. Schmutz (1987) found ferruginous hawks would leave the nest when humans came within 120 yards. Impacts from training are related to disturbance at nesting sites and to destruction of vegetation and soil resources that reduce availability of their prey.

167. Swainson's hawk. The Swainson's hawk prefers open prairie, plains, and desert, and eats a variety of food items (Schmutz 1987). In an agricultural area of southeastern Washington and in a shortgrass prairie in

Wyoming, their primary prey was small mammals with birds taken secondarily (Dunkle 1977, Bechard 1983). The Wyoming study also recorded several other animal groups as food. Swainson's hawks nest in trees (Dunkle 1977) and on rocky outcrops. This raptor does not seem to be as sensitive to human disturbance as others; Schmutz (1987) found it would flush from the nest when humans approached within 20 yards. Ten nesting sites have been identified on the YFC, and are accessible to and could be impacted by training vehicles during nesting.

168. Sage grouse. Autenrieth (1986) reviewed habitat requirements and population status of the sage grouse and is the source for the following information unless otherwise stated. This species requires sagebrush for cover for nesting, wintering, loafing, and escape, and for food. Nests are on the ground. In addition to adequate cover and size of sagebrush (optimally 35 percent and two feet high), nesting and brood-rearing habitat require herbaceous vegetation which provides forbs, seeds, and insects. Broods usually move to moist areas such as vegetated seeps or riparian meadows in the summer to assure an adequate source of seeds and insects. A third habitat requirement is a sparsely vegetated area near cover for breeding (the lek). The same location may be used as a lek year after year, although yearling birds may disperse and establish a new lek (Gates 1985). Two traditional leks exist on the YFC (Plate 61) and perhaps an additional nine were located in the spring of 1989 by personnel from Battelle (Table 9).

169. Leks are located in openings in the brush; such open areas are probably not limiting on the YFC because of adequate disturbance from vehicles or fire (i.e., some training impacts may be beneficial). Two of four limiting factors to the population are in action on the YFC: habitat loss from wildfires, and sagebrush eradication (not as a program but from vehicle damage). Cited information in Braun, Britt, and Wallestad (1977) documents sharp declines in breeding, nesting, brooding, and wintering birds with sagebrush control, e.g., "a 31 percent loss of habitat adjacent to a lek coincided with a 63 percent decline of strutting males in Montana". Sage grouse are highly dependent on sagebrush/grasslands and will not exist on the YFC if the sagebrush communities are impacted beyond the birds' minimum requirements for survival.

170. Burrowing owl. Unless otherwise stated, the following information is from Green (1983). The burrowing owl is an open plains owl that uses

burrows dug by mammals, with a historic dependence on prairie dog dens (Evans 1982). It will also nest in abandoned badger, coyote, and large ground squirrel dens. Burrowing owls perch near their nests during the day, then hunt over the prairie for arthropods and small vertebrates, primarily mammals. Nesting habitat is selected not because of the presence of burrows, but on vegetative characteristics such as horizontal visibility and relatively low coverage of grass, sparse vegetation overall, and perch sites. There was also a requirement that pairs be separated by at least 120 yards in Green's northern Oregon study area.

171. Impacts on this species could already be severe at the YFC with existing training levels, since their nest burrows are not highly visible and the species nests primarily outside NOGO zones. Compaction of the soil from a vehicle tire or track directly over the burrow and its runway will likely destroy the burrow's contents. Excessive traffic could crush enough burrows that they become a limiting factor to the owl, but burrows in loamy sandy soils that are caved in may only require that the burrow be dug out for reuse, so light traffic may not have a great impact. Four active burrow sites have been identified on the YFC. Increased training levels and therefore increased numbers of passes will increase the likelihood of severe disturbance.

172. Merrian's shrew. This small mammal has been noted in two areas on the western side of the YFC. There are probably more of this species on YFC; Zeveloff (1988) calls it widely distributed in the west, although populations are sparse and Rogers et al. (1988) did not catch any. The Merriam's shrew eats several kinds of insects (Zeveloff 1988). It has a relationship to the sagebrush vole in that the shrew searches vole burrows and runways for food. Impacts from training increases would range from vehicles crushing nests and young to long-range impacts of changing vegetation and reducing sagebrush voles and their burrows, to increased bare ground reducing insects.

173. Sagebrush vole. The sagebrush vole requires sagebrush shrubland habitat to meet basic life requirements of cover and nest sites. It nests under sage tunneled within the root systems, and uses sagebrush bark in its nest (Mullican and Keller 1986). Ten vole stomachs analyzed by Mullican and Kewler (1986) in June and August contained predominately clovers (Lupinus spp.) and Indian paint brush (Castilleja spp.) with trace amounts of sagebrush.

174. The WNHDS supplied four observations on the YFC (Table 8), which is probably a lower record than exists. The animals are secretive and undoubtedly seldom seen unless trapped. Rogers et al. (1988) trapped voles immediately north of the YFC in October-December 1987, and animals were found on 8 of 14 trap lines. The most animals were caught on ridgetops in stiff sage (ten) and in draws with big sagebrush (six). Eleven voles were caught in stands of sagebrush or mixed sagebrush and bluegrass. Data were presented as total number captured; it is not clear if all 27 were different animals or recaptures. Impacts on this species would include crushed nests from traffic over the rangeland, and loss of sagebrush cover.

175. Sagebrush. The upper reaches of the intermittent creeks and their dry washes are vegetated with big sagebrush and a variety of understory grasses and forbs. Sagebrush is greatly impacted on an area such as YFC in several ways. First, it is crushed or damaged by training vehicles. Second, wildfires that arise from training top-kills or damages sagebrush. Third, as it tries to regenerate from roots or crushed stems, it is eaten by livestock and certain species of wildlife. Fourth, where bare ground areas are exposed, wind and water erosion removes topsoil from these dry washes and hilly slopes, and the sagebrush cannot form adequate root systems or maintain itself on eroded soils.

176. Riparian. The creeks on YFC have varying amounts of riparian vegetation. These areas are usually dominated by black cottonwoods, willows, and other typical riparian species, although big sagebrush is also common. Presently, these riparian zones are not excluded from the YFC grazing program or from training use. Where enclosures have been established, on YFC and at other locations, a dramatic difference generally is evident between outside and inside the fenced enclosures (e.g., Platts and Nelson 1985). However, on some degraded riparian stretches, excluding grazing and traffic may not be sufficient to restore wetland vegetation. Either structural measures will be necessary to restore flow, or vegetation management will be required to replace the cheatgrass.

177. The riparian areas that are accessible (such as Selah Creek) are greatly affected by training, driving in the creekbed, and other uses. Continuous coverage of typical riparian vegetation does not occur in these areas, and there are areas with severe erosion. The shift to different force structures and higher training intensities will magnify this problem.

178. Further degradation of the riparian area may be caused by fording or crossing sites. Based on the YFC special map, there are only 11 designated fords (Plate 63). Four of these are located on North Fork of Squaw Creek at UTM coordinates 076902, 085898, 094900, and 107896. Hanson Creek also has four designated fords, located at coordinates 182874, 200869, 268848, and 277845. The final three sites are on Squaw Creek at coordinates 068835, 071832, and 076828.

179. Because of the lack of vegetation on North Fork Squaw Creek, the major impact will be erosion. Both Hanson and Squaw Creeks will be affected by erosion and vegetation impacts. Disturbance and activity at the fords on Squaw Creek may also impact the lek area, which is near.

180. Perhaps the most serious impacts from fords and crossings are those that occur at undesignated sites. In many cases, sites that started out as single-width crossings have been expanded to multiple crossings. In other cases, vehicles use these crossings to enter the streambed, which is then used as a road. These actions cause extreme damage to the riparian area in the form of severe erosion along the channel banks, increased siltation during precipitation events, and discontinuity of riparian vegetation.

181. Springs and seeps. There are 154 springs, 16 seeps with ground water near the surface, and 2 ponds located on YFC. These all have wetland or vegetation communities different from the surrounding steppe vegetation, and can be severely impacted by either training or from grazing domestic animals. The springs and seeps may or may not be associated with streams. For example, Borden Springs is a cluster of flowing springs at mid-slop of a hill facing the Columbia River that is the result of water moving within the rock substrate along uplifted layers and emerging where those layers are exposed. Even use by several individuals will have an impact on springs and seeps, so excluding vehicle traffic is not sufficient.

182. Rocky Areas. The highest slopes and ridges of the YFC are either bare rock surfaces or rock pavement (soil overlain with a weathered surface of small rocks). If surfaces are undisturbed, there will be minimal erosion. However, even on pass of any training vehicle over such surfaces in wet weather causes significant impacts. In dry weather, surface and other loose rocks are displaced, exposing the soil beneath. This exposed bare soil will immediately become subject to wind erosion. Vegetation will be affected regardless of wet or dry conditions, and at such elevations and harsh climatic

conditions, vegetation may take decades to re-colonize the disturbed area. An example of these fragile areas is the stiff sage community, underlain with rock pavement. Another example is talus slopes, which are highly prone to slides and impacts from disturbance. However, in most cases, talus slopes represent NOGO areas.

183. The cliffs of Selah Creek Canyon, Alkali Canyon, and the Columbia River provide unique habitats in the YFC area for raptors. These areas can be impacted during the nesting season by traffic either at the base of the cliffs (in the canyons) or along the tops near the cliff edge.

Recommendations

184. Because of the apparent existence of disturbance thresholds in the force structures evaluated, and also because of the time, expense, and unpredictability of restoration efforts, vehicle use should be concentrated on resistant areas and during times when traffic causes the least damage. Location and timing of new activities should be planned giving consideration to soil, water, and biotic resources as well as training needs. Proper timing of training exercises is critical because it reduces damage and prolongs the life of the training area, as well as reducing vehicle wear and tear and increasing safety. Defining the most appropriate location and timing related to resources requires consideration of interactions and trade-offs, as illustrated in Table 14. At the YFC, it may not be possible to both train and avoid some forms of environmental damage.

185. Priorities on natural resources should begin with the soil base and strongest efforts to preserve it; specifically, these should include vehicle control and maintenance and reestablishment of vegetation. For example, from the standpoint of soil compaction, disturbance, and water erosion, traffic in and immediately following the wet season (December through March) should be minimized. During the wet season, areas with the most shallow soils should be avoided. Because of wind erosion, traffic should be minimized in September through November. Maintenance of vegetation in the dry climate of the YFC is easier than its reestablishment. Plant height, diameter, and density interact with wind velocity to determine soil loss (van de Ven, Fryear, and Spaan 1989). In a wind tunnel simulation, even short, thin, sparse "vegetation" reduced soil loss by 60 percent compared to bare soil.

Table 14
Occurrence of Various Activities

Activity	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
Precipitation ¹	###	///	///	///	///	///	---	---	---	///	///	%%
Plant dormant season ²	XXX	XXX	XXX	XXX						XXX	XXX	XXX
Soil susceptibility to compaction ³	///	###	###	///	---	---	---	---	---	---	///	///
Potential wind erosion ³	---	---	---	///	---	---	---	///	###	###	###	///
Potential water erosion ³	///	###	###	///	---	---	---	---	---	---	---	///
Sage grouse breeding ⁴		XXX	XXX									
Sage grouse nesting ⁴			XXX	XXX	XXX	XXX						
Raptors nesting ⁵			XXX	XXX	XXX	XXX	XXX	XXX				
Sagebrush vole nesting ⁶			XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Merriams shrew nesting ⁶		XXX	XXX	XXX	XXX	XXX						

1. --- = <.5 in., /// = .5-1 in., %% = 1-1.5 in., and ### = >1.5 in.
2. Based on Soil Survey of Yakima County Area, Washington (USDA 1985). Dormant season is from date of first freezing temperature in fall, 5 of 10 years, at 28 F or lower, to date of last freezing temperature in spring, 5 of 10 years, at 28 F or lower.
3. --- = Low, /// = Moderate, and ### = Severe.
4. Autenrieth (1986).
5. Rogers et al. (1989).
6. Zeveloff (1988).

186. A second but related priority is avoiding or reducing the amount of vegetation loss, both to avoid further soil degradation and for wildlife habitat. To reduce damage to plant growth, the month of May should have minimal traffic because this is when plants break dormancy in response to moisture and rising temperature.

187. A third priority is avoiding training-induced changes in vegetation composition, which is also closely related to soil and wildlife. Introduced species such as knapweed and cheatgrass offer little soil protection or wildlife value. Maintaining the maximum number of layers (substrate,

herbaceous vegetation, shrubs) will help preserve species richness and reduce wind and water erosion.

188. Another priority which is somewhat addressed by the other priorities and can often be worked into training guidelines should be on animal species. Attention should be given especially to breeding and nesting requirements for sage grouse and raptors. Scheduling activities and creating buffers to avoid key areas will help eliminate undesirable effects.

189. The remaining recommendations pertain largely to special areas of concern and the resources listed in Table 8. All recommendations on protection of a natural feature are predicated on field verification of the condition and extent of the feature. Recommendations from the literature were converted from metric to standard measures and rounded upward.

190. Riparian areas. The major need in the riparian zone is for the elimination of traffic in the stream beds. With that measure, adequate restrictions on grazing, and fire control, existing vegetation in the riparian areas should be adequately considered. Specific features of this zone should be identified and preserved, especially trees that may be nest sites for ferruginous and Swainson's hawks. Riparian vegetation that is in proximity to leks, cliffs, or other wetland vegetation should be included in this highest priority.

191. Fords and roads. If the lek is still being used, the two fords on Squaw Creek that are adjacent to the lek should be discontinued, if possible. This could be accomplished by rerouting traffic around the lek area. All other currently designated fords should be improved, using either locally available rock/cobble, or hardened with concrete. Additional crossing sites (only in areas that are necessary) on other streams should be officially designated and improved. These should be located so as to avoid riparian vegetation, highly erosive conditions, and areas of special interest for plants and animals. All other crossings should be prohibited.

192. In addition to improving the crossing sites, all major roads within the YFC should be improved to control dust and erosion. Improved roads would also reduce the current problem of drivers blazing their own trail.

193. Off-limits areas. All springs seeps, ponds and areas with wetland vegetation should be considered for off-limits designation for vehicles. It will be necessary to establish a ranking system to determine which receive

protection and in what order. Factors for that ranking could include riparian discontinuity, degree of incision, distance to cliffs, proposed training and its access points, etc. Special attention should be given to Borden Springs and those seeps or springs that are critical, i.e., those that represent the only water source for a large area.

194. All rocky slopes and cliffs, especially those in the northeast corner and along alkali, Selah, and North Fork Squaw Creeks should be off-limits for all training. This will offer protection for several of the sensitive plants and prevent disturbance of golden eagles and the other raptors.

195. The current special use area for Columbia milk-vetch (below Borden Springs) should be continued and expanded to include additional sites in Training Areas 5 and 6B.

196. Sagebrush Community. Recommendations are given in Autenreith (1986) for the control of sagebrush when other land uses require such a program. By the end results, military vehicle traffic can be equated to sagebrush control programs. Recommendations include defining a breeding complex of lek and potential nesting area as a circle two miles in radius from the lek. No control should be performed within that area. Also, a 400 yard buffer of sagebrush should be left along edges of drainage and meadows (i.e., riparian and seeps and springs), and all sage should be left on slopes greater than 20 percent with shallow soils where sage is less than a foot tall. Important sage grouse wintering concentrations should be located and not impacted. In addition, an area of one mile in radius from the lek should be posted to lessen impacts during the breeding months of February through May.

197. Other recommendations. Discussions on the advisability of additional recommendations are needed with wildlife and range personnel from the YFC. Points for discussion include: feasibility of fencing of specific environmental NOGO areas, reclamation of the most disturbed riparian areas, planting buffers along streambeds following severe disturbance from fire or vehicles, video-taping riparian and selected rangeland locations prior to implementing the proposed changes in force structure, and refinement of soil erosion and soil productivity loss predictions using the YFC soil map.

TAB 1

Approach to Riparian Mapping and Results

Prepared by Shapiro and Associates, Inc., Seattle, WA
June 1989

Approach

Existing information describing the riparian vegetation communities of YFC includes: the National Wetland Inventory Maps for YFC (U.S. Fish and Wildlife Service, 1976-1981), YFC Natural Resource Land Management Plan (Shapiro and Associates, Inc., 1987), Vegetation Survey for the Potential Impact Area Relocation at the Yakima Firing Center, Washington (Boule, 1982), and Steppe by Step, Understanding Priest Rapids Plants (Mastrogriuseppe and Gill, 1983). In addition, the topographic quadrangles for YFC (1:24,000) (U.S. Geological Survey, 1948, 1953, 1965, 1978, and 1985), and color aerial photographs of YFC flown on June 8, 1982 (and in limited areas on May 29, 1977) provided information on topography, distribution of riparian habitat types, and cultural features. All this material was reviewed prior to starting aerial photograph interpretation.

Aerial photographic interpretation began with the preparation of a base mylar overlay for each USGS Topographic Quadrangle in the study area. The base overlay was created by securing a mylar sheet over topographic map. Reference points, such as the quadrangle boundaries, roads, mines, dominant ridge tops, and other identifiable features were then traced onto the mylar overlay. Riparian vegetation community types were delineated on the mylar overlays using stereoscopes to view the aerial photographs. Tone, texture, and density were used as the photographic characteristics, or signatures, to distinguish one vegetation community from another. Field observations and photo interpretation indicated that riparian zones greater than 200 ft in width can be delineated on the overlay to actual size (1:24,000 scale). Riparian vegetation zones less than 200 ft in width cannot be accurately represented at this scale and were displayed as linear features. These linear feature riparian zones were labeled as either 100-200 ft wide, or <100 ft wide.

Draft vegetation maps were completed in pencil and copied as blueprints for field use. Field surveys were conducted to verify preliminary habitat classifications, and to verify photographic signatures of different plant communities. In areas where a mixture of habitat types was evident, the two dominant habitat categories were identified on the map and separated by a slash. In these instances, the first habitat type was dominant and the second was primary subordinate. In areas where there was a mixture of habitat types, but the subordinate habitat comprised less than 15 percent of the total cover, only the dominant habitat classification was used to identify the community. The dominant and common subdominant plant species of each community type are identified in the plant community narrative section.

Field sites for verifying the draft vegetation map were chosen both at random and in locations where questionable habitat types or boundaries were identified on the aerial photographs. The draft vegetation map was field checked using a four-wheel drive truck for one day, primarily following Squaw

and Hanson Creeks. Much of the study area is inaccessible due to the steep terrain. Thus the remainder of the draft map verification was completed during five days of helicopter surveys. The helicopter was flown at an altitude of approximately 100-200 ft within selected canyon areas for the verification of the vegetation map, and notes were placed on the field maps. Topographic maps were used to determine the locations of vegetation types and the sample plots. The helicopter landed when it was necessary to obtain vegetation plot data, or to survey a riparian reach in more detail.

Plots were established to be representative of the vegetation within each habitat type. At each field location, a vegetation plot was established by visual estimation, with size of the plot dependent on the type of vegetation. For example, a 10 by 10 m area was used for forested areas, a 2 by 2 m area was used for shrubs, and a 1 by 1 m area for forbs and grasses. Data collected at each plot included type of vegetation community, percent cover of dominant and subdominant plant species, map location, date, perception of disturbance, surface soil texture, notes on landform and topography, and any relevant observations. Percent cover for trees, shrubs, and forbs within each plot was determined by visual estimation of each species within each vegetative layer. The texture of the surface soil was determined by field estimates within the vegetation plot. Photographic slides of representative vegetation communities were also taken at most plots. Information recorded for each photograph included location, date, time of day, habitat classification, direction of photograph, and any relevant observations. Representative photos were numbered to cross-reference the field data sheets.

All of the main canyons and many of the tributaries to the east-side canyons (particularly tributaries to Alkali, Corral, and Sourdough Creeks) were flown in the helicopter to verify the vegetation maps. Information for Alkali Canyon and its tributaries is especially detailed because of the extensive areas of riparian vegetation present. Bands of riparian vegetation in narrow, steep canyons not evident from the aerial photographs required additional field time to maintain mapping accuracy. Detailed field notes were used to improve the precision of the aerial photograph interpretation.

Data on the perception of disturbance and erosion was collected by flying slowly along all the main canyons and major tributaries within the study area where access allowed. Topographic maps and the draft vegetation maps were used to determine the location of disturbance and erosion zones. The disturbance and erosion estimates represent the most severe erosion and disturbance observed within that reach. Disturbance data were not collected on the reach of Squaw Creek within the impact area because of access restrictions.

RESULTS

Study Area

YFC is a 260,000 acre military reservation located approximately 10 miles north-east of the city of Yakima, in central Washington. It is bounded on the north by the Saddle Mountains and on the east by the Columbia River. The southern boundary is along Yakima Ridge, and most of the western

bounded on the north by the Saddle Mountains and on the east by the Columbia River. The southern boundary is along Yakima Ridge, and most of the western boundary is along Interstate Route 82. The study area included all riparian areas within the YFC boundary (Figure 3).

The Saddle Mountains and Umtanum Ridge are the major topographic features within the study area, with elevations reaching 4,000 ft. Most of the area is characterized by east to southeast-trending basalt ridges with trough-like valleys. In general the ridges have steep north-facing slopes and flat, gentle south-facing slopes. These topographic characteristics are controlled by highly eroded southward dipping basalt beds.

The climate of the study area is characterized by hot, dry summers and cold, dry-to-moist winters. Precipitation is about 4 to 6 in. per year, most of this occurring between fall and spring. Accordingly, there is little surface water and only a few streams are considered perennial. Springs and seeps are sparse and scattered; many do not flow all year.

Prior to the Army's acquisition of the area, the land was heavily grazed by cattle and sheep. This overgrazing degraded and reduced the area of the native grasslands, damaged riparian zones, and accelerated erosion. In addition to overgrazing, range fires have eliminated shrubs and herbaceous species in many areas. Since the Army's acquisition of YFC, range management programs have reduced overgrazing and allowed some areas to recover. Dramatic results of reestablished vegetation are evident where fences have been erected to prevent livestock from entering riparian zones.

Riparian habitats occurring on the YFC vary depending on the location, terrain, type and severity of disturbance. Generally, the western half of the reservation supports riparian habitat mainly in the downstream portions of the two intermittent creeks, Squaw and Selah. Emergent, scrub-shrub, and forested wetland communities occur within these creek corridors. Numerous ephemeral drainage occur on the western side of the reservation and eventually drain into either Squaw Creek or Selah Creek. These ephemeral drainages and the upper portions of Squaw Creek and Selah Creek do not support riparian vegetation and are commonly used as roads. The eastern portion of the reservation is characterized by steep northeast-facing ridges which are laced by an intricate network of drainage and canyons. Five main creeks flow to the Columbia River; Hanson Creek, Alkali Creek, Coral Creek, Sourdough Creek, and Cold Creek. Hanson Creek and Alkali Creek are the only perennial creeks. Seeps, emergent, scrub-shrub, and forested wetland communities are common in the upper reaches, along the main stem of tributaries, and in the main creek corridors. A list of plant species identified during the field visits is presented in Appendix A. The data from the vegetation plots and the photograph log are presented in Appendix B and C, respectively.

Vegetation Classification

Vegetation classifications used for riparian areas at YFC correspond to the U.S Fish and Wildlife Service's Wetland Inventory classification system (Cowardin et al. 1979). The habitat types delineated on the mylar overlays were identified from color aerial photographs at 1:24,000 scale, or discovered during ground truth verification and helicopter flights. Modifiers to the

U.S. Fish and Wildlife codes were used to describe the width and extent of the identified riparian communities. These classifications are described below.

Forested Wetland (PFO)

The dominant tree species occurring in this community varied depending on the location, terrain, and level of disturbance. Generally, forested wetland areas occurring on the western side of the reservation are dominated by black cottonwood (Populus trichocarpa), alder (Alnus sp.), and occasionally water birch (Betula occidentalis). The understory typically is composed of willow (Salix spp.), stinging nettle (Urtica dioica), teasle (Dipsacus sylvestris), sweet clover (Trifolium spp.), horetail (Equisetum sp.), soft rush (Juncus effusus), spike rush (Eleocharis palustris), watercress (Rorippa nasturtium-aquaticum), speedwell (Veronica anagallisquatica), and curly dock (Rumex crispus). A band of emergent vegetation in and along the edge of the creek bed is common under this canopy. This community is present along the lower portions of Squaw Creek and Selah Creek on the western portion of the reservation.

On the eastern side of the reservation, the canopy is dominated by black cottonwood or water birch. In the upper reaches of the tributaries and canyons, aspen (Populus tremuloides) occasionally is the dominant overstory species. The understory of forested riparian areas on the eastern side typically consists of willow, rose (Rosa sp.), golden currant (Ribes aureum), squaw currant (Ribes cereum), mockorange (Philadelphus lewisii), and clematis (Clematis sp.). Groundcover in this community is commonly composed of clover, fireweed (Epilobium angustifolium), stinging nettle, teasle, dock, soft rush, spike rush, horsetail, and red columbine (Aquilegia formosa). On the eastern side of the reservation, this forested community occurs in patches along the main canyons and the upper reaches of the tributaries. The extent of forested wetland has been reduced since the aerial photographs were taken in 1977 and 1982 as a direct result of fire.

Scrub-shrub Wetland (PSS)

This community is the most prevalent in the riparian areas. Willow is the dominant plant with mockorange, squaw currant, golden currant, chokecherry (Prunus virginiana), and serviceberry (Amelanchier alnifolia) occurring to a lesser degree. Typical groundcover consists of stinging nettle, sweet clover, teasle, horsetail, fireweed, monkey flower (Mimulus glabratus and M. floribundus), vetch (Vicia sp.), goldenrod (Solidago sp.), yarrow (Achillea millefolium), speedwell, and cattail (Typha latifolia). Sumac (Rhus glabra), dogwood (Cornus stolonifera), and poison oak (Rhus radicans) are occasional components of the scrub-shrub community in the riparian areas of the eastern side of the reservation.

Emergent Wetland (PEM)

This community typically occurs in reaches between scrub-shrub and forested communities where the flow of the creek is slower and ponding occurs. This community is composed of soft rush, spike rush, rushes, (Juncus spp.), sedges (Carex spp.), cattail, watercress, speedwell, dock, bulrushes (Scirpus americanus and S. microcarpus), water parsley (Oenanthe sarmentosa), duckweed

(Lemna minor), horsetails (Equisetum spp.), monkey flower, blue grass (Poa sp.), teasle, stinging nettle, sweet clover, and ryegrass (Elymus cinereus).

Riparian Stream Bed (RSB)

This classification code describes those areas which do not support riparian vegetation. The drainage consists of either exposed rock or upland vegetation such as big sagebrush (Artemista tridentata), rabbitbrush (Chyrsothamnus spp.), lupine (Lupinus sulphureus), cheatgrass (Bromus tectorum), and buckwheat (Eriogonum spp.). A riparian stream bed code with a "V" modifier is dominated by upland vegetation; an "N" modifier denotes riparian area composed of exposed rock. An unclassified riparian stream bed represents a drainage which does not support riparian vegetation, but was not surveyed by helicopter. Stream bed areas along Squaw and Selah Creeks are commonly used as roads. With the exception of Hanson Creek, similar areas on the eastern side of the reservation generally are less disturbed. Hanson Creek is heavily grazed by livestock and subject to a high concentration of military traffic and camping.

In addition to military training operations, areas outside of the impact zone at YEC are used as open range for livestock. Much of the riparian areas are heavily grazed and thus, many of the plant species previously mentioned are browsed and trampled. Some of the riparian areas have been fenced to exclude vehicles and livestock for wildlife preservation. The vegetation in the enclosure areas tends to be much denser, lusher, and healthier than the vegetation outside the enclosure areas.

Disturbance Classifications

Four classifications of disturbance are used for the riparian maps: (1) L for domestic livestock grazing activity; (2) M for mechanical disturbance such as roads or vehicle crossings of creek beds; (3) C for cheatgrass, where the cause of the disturbance is unknown, but is evident from this exotic grass species which colonizes disturbed sites; and (4) F for fire.

For each of these disturbance classifications there are 3 modifiers: (1) indicates low level disturbance; (2) indicates moderate disturbance; and (3) indicates high disturbance. The lack of a disturbance classification symbol indicates no disturbance. These disturbance classifications are described below.

Low level disturbance for livestock indicates some evidence of past grazing was observed such as: old cow scat, scattered livestock trails, and vegetation which has not recovered fully. A moderate livestock disturbance indicates more recent grazing, a greater reduction of native plant species, and a greater frequency of livestock trails. A high livestock disturbance indicates recent or current grazing activity, recent evidence of livestock browse, fresh manure, and reduced ground cover.

A low level of mechanical disturbance indicates a reach where vegetation is reestablished in an old stream crossing, roads near creeks do not encroach on the riparian zone, and past off-road vehicle activity is limited. Moderate mechanical disturbance represents an area with a higher frequency of stream crossings and roads that encroach upon the riparian zone. High mechanical

disturbance represents a reach in which the stream bed is used as a road, and numerous stream crossings exist.

A low level of cheatgrass represents small scattered patches, a moderate level represents larger patches of cheatgrass, and a high level represents areas dominated by cheatgrass with little native vegetation. Visual estimation of the extent of cheatgrass was used to determine the level of disturbance.

A F indicates disturbance by fire, with a low, moderate, or high modifier assigned depending on the evidence of damage to vegetation. Other indicators such as the amount of cheatgrass and erosion were also used to estimate the extent of fire damage. Evidence of fire is not apparent from the helicopter unless it has occurred in a forested area and charred trees are present. Fire disturbance is noted only in areas which could be detected from the air or where ground inspection was conducted.

Erosion Classifications

For riparian plant communities to remain vigorous, the stream with which they are associated must not be excessively unstable. In general, channels should be sized to carry a peak discharge that has a recurrence interval of one and one-half to three years. As an indication of channel stability, the degree of incision along stream corridors was cataloged at the same time disturbance level was calculated. Erosion is indicated by an E on the map and numbered modifiers refer to the depth of erosion within the creek bed. one represents an erosion depth of 0-2 ft, 2 represents 2-6 ft, 3 represents 6-12 ft, and 4 represents erosion of 12 ft or greater. The modifier u is used to indicate areas of erosion with unpaired terraces. This modifier indicates a bend of the creek where erosion is taking place on one side and sedimentation or no erosion on the opposite side.

For purposes of future riparian zone stabilization, these erosion categories correspond to: (1) stream banks which are able to convey normal stream flow peaks; (2) banks of incised channels which can be stabilized by shrubby vegetation alone; (3) incised channels which are likely to require structural stabilization of the channel bed prior to vegetative recovery; and (4) incised channels which may require structural stabilization of both stream bed and banks. These classes are loosely based on descriptions of rehabilitation techniques provided by Heede (1981, 1982). In areas where livestock and vehicles are excluded, incised channels are in the process of stabilizing naturally. Healthy riparian communities can be found within some of the deeply incised channels. Cold Creek, in the southeastern corner of the reservation, is an example of this phenomenon. Therefore, the erosion index is only an indication of those areas which may require rehabilitation.

Habitats of Special Concern

A few seep areas are scattered throughout YFC, with the highest concentration found in the eastern canyons. The species common to this community include juniper (Juniperus scopulorum) and a combination of species typical of scrub-shrub areas. Seeps usually are found on the side of steep canyon walls or in the upper reaches of tributaries on the eastern side of the reservation.

A number of seep areas found along Alkali Canyon, Corral Canyon, Sourdough Canyon, and Cold Canyon and their respective tributaries have been greatly altered by fire. Junipers were a common component of most seep areas prior to recent fires on the reservation. The few vegetated seep areas which formerly existed in many of the seep areas. Juniper regeneration was not observed in either of the areas where mature juniper and burned juniper stumps occur.

The largest and most diverse spring area at YFC is Borden Springs. The variety of community types and oasis-like character of this area provide valuable habitat for wildlife. Most of the area is inundated with water; several small creeks flow through the area to the Columbia River. Sedge, rush, bulrush, and marsh grasses make up the majority of this marsh community. Junipers and scrub-shrub community also occur. Several plant species of concern to Washington Natural Heritage Program have been identified at Borden Springs by Mastroguiuseppe and Gill (1983).

The few open water ponds scattered along a few of the main creeks are also extremely valuable areas for wildlife. Forested or scrub-shrub and emergent communities typically surround the open water. Exclosure fences surround several of these areas. Ponded areas not only provide wildlife habitat, but also help to reduce sedimentation and erosion of the creek.

The entire eastern portion of the reservation is a region of special concern due to the relatively low level of disturbance and existing riparian communities. Mastroguiuseppe and Gill (1983) have identified species of concern in this part of the reservation.

REFERENCES

- American Society for Testing and Materials. 1985. "Standard for Metric Practice," Designation: E 380-85, Philadelphia, PA.
- Andersen, E. N. 1984. "Livestock Grazing Outlease Operations at Yakima Firing Center, Yakima, WA", Internal Working Document, Fort Lewis, WA.
- Autenrieth, R. E. 1986. "Sage Grouse." Pages 763-779 IN: A. S. Eno, R. L. Di Silvestro, and W. J. Chandler, eds. Audubon Wildlife Report 1986, National Audubon Society, New York.
- Bagnold, R. A. 1941. The Physics of Blown Sand and Desert Dunes. London, Methuen.
- Bechard, M. J. 1983. "Food Supply and the Occurrence of Brood Reduction in Swainson's Hawk," Wilson Bull Vol 95, No. 2, pp 233-242.
- Bolen, E. G. 1975. "Eagles and Sheep: A Viewpoint," Journal Range Management, Vol 28, No. 1, pp 11-17.
- Brady, N. C. 1974. The Nature and Property of Soils, 8th Edition. MacMillan Publishing Company, New York, p 639.
- Braun, C. E., Britt, T., and Wallestad, R. O. 1977. "Guidelines for Maintenance of Sage Grouse Habitats," Wildlife Society Bulletin, Vol 5, No. 3.
- Brown, E. R., Editor. 1985. "Management of Fish and Wildlife Habitats in Forests of Western Oregon and Washington, Part I: Chapter Narratives, and Part II: Appendices," Publication No. R6-F&WL-192-1985, USDA Forest Service, Washington, DC.
- Browning, G. M., Parish, C. L., and Glass, J. 1947. "A Method for determining the Use and Limitations of Rotation and Conservation Practices in the Control of Soil Erosion in Iowa," Journal, American Society of Agronomy, Vol 39, pp 65-73.
- Bury, R. B., Luckenbach, R. A., and Busack, S. D. 1977. "Effects of Off-road Vehicles on Vertebrates in the California Desert," Wildlife Research Report No. 8, US Fish and Wildlife Service, Washington, DC.
- Call, M. 1979. "Habitat Management Guides for Birds of Prey," T/N 338, US Department of Interior Bureau of Land Management, Denver, CO.
- Chepil, W. S. 1945. Dynamics of Wind Erosion III. Transport Capacity of the Wind," Soil Science, Vol 60, pp 397-411.
- Chepil, W. S., and Woodruff, N. P. 1963. "The Physics of Wind Erosion and Its Control," In: Advances in Agronomy, Vol 15, E. A. G. Norman, pp 211-303, New York, Academic Press.
- Chew, R. M. 1978. "The Impact of Small Mammals on Ecosystem Structure and Function," pp 167-180 IN D.P. Snyder, ed., Populations of Small Mammals Under Natural Conditions, Vol 5, Special Publication Series, Pymatuning Laboratory of Ecology, University of Pittsburgh, PA.
- Cole, D. N. 1979. "Reducing the Impact of Hikers on Vegetation: An Application of Analytical Research Methods," IN Prod. Recreational Impact on Wildlands, Technical Report R-6, USDA Forest Service, Portland, OR.

- Collopy, M. W. 1983. "A Comparison of Direct Observations and Collections of Prey Remains in Determining the Diet of Golden Eagles," J. Wildl. Manage., Vol 47, No. 2, pp 360-368.
- Cooke, R. U., D. Brunsden, J. C. Doornkamp and D. K. C. Jones. 1982. Urban Geomorphology in Drylands, New York: Oxford University Press.
- Dawson, J. O., Countryman, D. W., and Fittin, R. R. 1978. "Soil and Vegetative Patterns in Northeastern Iowa Campgrounds," J. Soil and Water Conservation, Vol 33, pp 39-41.
- Department of the Army. 1978. Training Land, TC 25-1, Washington, DC, p 166.
- Dunkle, S. W. 1977. "Swainson's Hawks on the Laramie Plains, Wyoming," Auk, Vol 94, pp 65-71.
- Environmental Laboratory. 1986. "Field Guide to Low-maintenance Vegetation Establishment and Management," IR R-86-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS, p 150.
- Evans, D. L. 1982. "Status Reports on Twelve Raptors," Special Scientific Report No. 238, US Fish and Wildlife Service, Washington, DC, p 68.
- Freitag, D. R. 1965. "A Dimensional Analysis of the Performance of Pneumatic Tires on Soft Soils," Technical Report No. 3-688, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Gates, R. J. 1985. "Observations of the Formation of a Sage Grouse Lek," Wilson Bulletin, Vol 97, No. 2, pp 219-221.
- Goran, W. D., Radke, L. L., and Severinghaus, W. D. 1983. "An Overview of the Ecological Effects of Tracked Vehicles on Major US Army Installations," TR N-142, US Army Engineer Construction Engineering Research Laboratory, Champaign, IL.
- Goudie, A. 1983. "Dust Storms in Space and Time," Progress in Physical Geography 7, p 502-530.
- Green, G. A. 1983. "Ecology of Breeding Burrowing Owls in the Columbia Basin, Oregon," M.S. Thesis, Oregon State University, Corvallis.
- Harmata, A. R., Durr, J. G., and Geduldig, H. 1978. "Home Range, Activity Patterns, and Habitat Use of Prairie Falcons Nesting in the Mojave Desert," Unpublished report, US Bureau of Land Management, California Desert Program, Riverside, CA.
- Heede, B. H., Harvey, M. D., and Laird, J. R. 1988. "Sediment Delivery Linkages in a Chaparral Watershed Following a Wildfire," Environmental Management, Vol 12, No. 3, pp 349-358.
- Hilst, G. R., and Nickola, P. W. 1959. "On the Wind Erosion of Small Particles," American Meteorological Society Bulletin, Vol 40, No. 2: pp 73-77.
- Hitchcock, C. L., and Cronquist, A. 1973. Flora of the Pacific Northwest, University of Washington Press, Seattle, WA.
- Hudson, N. W. 1961. Soil Conservation, Cornell University Press, Ithaca, New York, p 320.
- Iverson, R. M., Hinckley, B. S., Webb, R. M., and Hallet, B. 1981. "Physical Effects of Vehicular Disturbance on Arid Landscapes," Science 212 (22): pp 915-917.

- Jasikoff, T. M. 1982. "Habitat Suitability Index Models: Ferruginous Hawk," US Department of Interior Fish and Wildlife Service, FWS/OBS-82/10.10.
- Kennedy, J. G., Rush, E. S., Turnage, G. W., and Morris, P.A. 1988. "Updated Soil-Moisture Strength Prediction (SMSF) Model," Technical Report GL-88-13, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Landin, M. C. and Doerr, T. B. 1983. "Vegetative Stabilization of Training Areas of Selected Western United States Military Reservations, Volume I, Technical Guide, and Volume II, Bibliography," Technical Reports furnished to the US Army Engineer Construction Engineering Research Laboratory, US Army Engineer Waterways Experiment Station, Vicksburg, MS, p 960.
- Lenfesty, C. D. and Reedy, T. E. 1985. "Soil Survey of Yakima County Area, Washington," USDA Soil Conservation Service.
- Marston, R. A. 1986. "Maneuver-caused Wind Erosion Impacts, South Central New Mexico" IN: W. G. Nickling (ed.), Aeolian Geomorphology, The Binghamton International Series in Geomorphology, No.17, Allen and Unwin: London, ENG, pp 273-290.
- Maser, C., Thomas, J. W., and Anderson, R. G. 1984. "Wildlife Habitats in Managed Rangelands--the Great Basin of Southeastern Oregon: The Relationship of Terrestrial Vertebrates to Plant Communities and Structural Conditions," Gen. Technical Report PNW-172, USDA Forest Service, Washington, DC, p 40.
- Mastrogioseppe, J. D. and Gill, S. J. 1983. "Steppe by Step: Understanding Priest Rapids Plants" Douglasia Occasional Papers, Washington Native Plant Society, Vol 1.
- McEwen D. and Tocher, S. R. 1976. "Zone Management: Key to Controlling Recreational Impacts in Developed Campsites," J. Forestry, Vol 24 pp 90-93.
- Merriam, L. C., Jr. and Smith, C. K. 1974. "Visitor Impacts on Newly Developed Campsites in the Boundary Waters Canoe Area," J. Forestry, Vol 72, pp 627-630.
- Meyer, L. S., Harmon, W. C. 1984. "Susceptibility of Agricultural Soils to Interrill Erosion," Journal of the Soil Science Society of America, 48, pp 1152-1157.
- Meyer, L. S., Zuhdi, B. A., Coleman, N. L., and Prasad, S.N. 1984. "Transport of Sand-sized Sediment along Crop-row Furrows," Transactions of the American Society of Agricultural Engineers, 26, pp 106-111.
- Mullican, T. R., and Keller, B. L. 1986. "Ecology of the Sagebrush Vole (Lemmyscus curtatus) in Southeastern Idaho," Canadian Journal of Zoology, Vol 64, pp 1218-1223.
- Musgrave, G. W. 1947. "The Quantitative Evaluation of Factors in Water Erosion-A First Approximation," Journal, Soil and Water Conservation, Vol 2, pp 133-138.
- Nuttall, C. J., Jr., and Randolph, D. D. 1976. "Mobility Analysis of Standard- and High-Mobility Tactical Support Vehicles (HIMO Study)," Technical Report M-76-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Ohmart, R. D., and Anderson, B. W. 1986. "Riparian Habitat," pp 169-199 in A. Y. Copperrider, R. J. Boyd, and H. R. Stuart, eds., Inventory and Monitoring of Wildlife Habitat.

- Olendorff, R. R., and Fish, A. M. 1985. "The Biology of the Ferruginous Hawk: A Review," US Department of Interior Bureau of Land Management, Unpublished Report, Sacramento, CA, p 96.
- Pacific Northwest Laboratories. 1988. Classified LANDSAT Vegetation Map, Yakima Firing Center.
- Payne, G. R., Foster, J. W., and Leininger, W. C. 1983. "Vehicle Impacts on Northern Great Plains Range Vegetation," J. Range Manage., Vol 36, No. 3, pp 327-331.
- Peterson, D. L. 1988. "Nesting and Habitat Parameters for Selected Raptors in the Desert of Northern Utah," M.S. Thesis, Utah State U. Logan, p 110.
- Platts, W. S., and Nelson, R. L. 1985. "Stream Habitat and Fisheries Response to Livestock Grazing and Instream Improvement Structures, Big Creek, Utah," Journal of Soil and Water Cons., Vol 40, pp 374-379.
- Prose, D. 1985. "Persisting Effects of Armoured Military Maneuvers on Some Soils of the Mohave Desert," Environmental Geology and Water Science, 1 (3): pp 163-170.
- Rasmussen, J. 1976. "Soil Survey of Yakima Indian Reservation Irrigated Area, Washington, Part of Yakima County," USDA Soil Conservation Service.
- Rigby, J. G. and Othberg, K. 1979. "Reconnaissance Surficial Geologic Mapping of the Late Cenozoic Sediments of the Columbia Basin, Washington: Open File Report 79-3," Washington State Department of Natural Resources, Division of Geology and Earth Resources, Olympia, Washington.
- Riggins, R. E. and Schmitt, L. J. 1984. "Development of Prediction Techniques for Soil Loss and Sediment Transport at Army Training Areas," Interim Report N-181, US Army Corps of Engineers, Construction Engineering Research Laboratory, Champaign, IL.
- Rogers, L. E., Beedlow, P. A., Eberhardt, L. E., Dauble, D. D., and Fitzner, R. E. 1988. "Ecological Baseline Study of the Yakima Firing Center Proposed Land Acquisition. Appendix B to Draft Supplemental Environmental Impact Statement, Yakima Firing Center Proposed Land Acquisition," Department of the Army, Headquarters I Corps and Ft. Lewis, Fort Lewis, WA.
- Rula, A. A., and Nuttall, C. J. 1971. "An Analysis of Ground Mobility Models (ANAMOB)," Technical Report M-71-4, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Schmutz, J. K. 1987. "The Effect of Agriculture on Ferruginous and Swainson's Hawks," J. Range Manage. Vol 40, No. 5, pp 438-440.
- Severinghaus, W. D., Riggins, R. E., and Goran, W. D. 1979. "Effects of Tracked Vehicle Activity on Terrestrial Mammals, Birds, and Vegetation at Fort Knox, KY," Special Report N-77, US Army Engineer Construction Engineering Research Center, Champaign, IL, pp 64.
- Shapiro and Associates, Inc. 1987. "Biological Report. Impacts to Bald Eagles, Sage Grouse, Swainson's Hawk, Long-billed Curlew, Ferruginous Hawk and Peregrine Falcon and Columbia Milkvetch, Hoover's Desert Parsley and Hoover's Tauschia Resulting from Acquisition of Additional Lands at YFC. Appendix C to Draft Supplemental Environmental Impact Statement, Yakima Firing Center Proposed Land Acquisition," Department of the Army, Headquarters I Corps and Fort Lewis, Fort Lewis, WA.

- Shapiro and Associates, Inc. 1989. "Yakima Firing Center Vegetation Mapping," Technical Report furnished to the US Army Engineer District, Seattle, WA, p 11 + app. and maps.
- Sheehan, M. and Clampitt, C. 1984. "Effects of Military Training Activities, Fort Lewis, Washington, on White-topped Aster (Aster curtus Cronq.)," Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.
- Sheridan, D. 1979. "Off-road Vehicles on Public Land," US Council on Environmental Quality, Washington, DC.
- Short, H. L. 1984. "Habitat Suitability Index Models: The Arizona Guild and Layers of Habitat Models," FWS/OBS-82/10.7, US Fish and Wildlife Service, Fort Collins, CO.
- Skidmore, E. L and Woodruff, N. P. 1968. "Wind Erosion Forces in the United States and Their Use in Predicting Soil Loss," Agriculture Handbook No. 346, US Department of Agriculture, Washington, DC.
- Smith, D. D. and Whitt, D. M. 1947. "Estimating Soil Losses From Field Area of Claypan Soil," Proceedings, Soil Science Society of America, Vol 12, pp 485-490.
- Turnage, G. 1973. "Using Dimensionless Prediction Terms to Describe In-Soil Tracked Vehicle Performance," Paper No. 73-1508, American Society of Agricultural Engineers, St. Joseph, MI.
- US Army Engineer Waterways Experiment Station. 1960. "The Unified Soil Classification System," Technical Memorandum 3-357, Vicksburg, MS.
- US Department of Interior. 1979. "Snake River Birds of Prey Study Area Summary Report," Bureau of Land Management, Washington, DC.
- Van De Ven, T. A. M., Fryrear, D. W., and Spaan, W. P. 1989. "Vegetation Characteristics and Soil Loss by Wind," J. Soil and Water Conservation, Jul-Aug, pp 347-349.
- Van Doren, C. A. and Bartelli, L. J. 1956. "A Method of Forecasting Soil Loss," Agricultural Engineering, Vol 37, pp 335-341.
- Wakeley, J. S. 1978. "Factors Affecting the Use of Hunting Sites by Ferruginous Hawks," Condor, Vol 80, pp 316-326.
- Washington Natural Heritage Program. 1989. Personal correspondence (unpublished information) from Ms. Nancy Sprague, Assistant Data Manager, 2 p + app.
- Willoughby, W. E. and Turnage, G. W. "Review of a Procedure for Predicting Rut Depth (in preparation)," US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Wilson, S. D. 1988. "The Effects of Military Tank Traffic on prairie: A Management Model," Environmental Management, Vol 12, No. 3, pp 397-403.
- Woodruff, N. P. and Siddoway, F. H. 1965. "Wind Erosion Forces in the United States and Their Use in Predicting Soil Loss," Agriculture Handbook No. 346, US Department of Agriculture, Washington, DC.
- Zeveloff, S. I. 1988. Mammals of the Intermountain West, University of Utah Press, Salt Lake City, pp 365.